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Energy and Precious Fuels Requirements of Fuel Alcohol Production

Volume III—Appendices C to F: Methanol from Cellulose

Rena Margulis and Geoffrey Back
Jack Faucett Associates

and

Karen St John and T. S Reddy
Battelle Columbus Laboratories

December 1982

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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U.S. DEPARTMENT OF ENERGY
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Office of Vehicle and Engine R&D

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FOREWORD

The study presented in this report was funded by the U.S. Department of Energy (DOE) and performed under Contract No. DE-AC01-80CS50005 with DOE and Contract No. DEN3-292 with the National Aeronautics and Space Administration (NASA) under Interagency Agreement DE-AC01-81CS50006. The work was performed by Jack Faucett Associates, with subcontractual assistance from Battelle-Columbus Laboratories and from the Center for Agricultural and Rural Development of Iowa State University. DOE responsibilities were carried out by E. Eugene Ecklund of DOE's Office of Vehicle and Engine R&D, and Dr. Daniel P. Maxfield of the same office assisted him. NASA responsibilities were carried out by George M. Prok of the Aerothermodynamic and Fuels Division at NASA-Lewis Research Center, Cleveland, Ohio.

ACKNOWLEDGMENTS

This report is the product of a team of persons from Jack Faucett Associates (JFA), Battelle-Columbus Laboratories (BCL), and the Center for Agricultural and Rural Development (CARD) of Iowa State University (ISU). Dr. Herbert Weinblatt and Michael F. Lawrence of JFA had overall responsibility for performing the study. Dr. Weinblatt had primary responsibility for final editing and for preparing Volume I and Appendices A and G of the report. Rena K. Margulis of JFA was responsible for Appendix E. Geoffrey Back of JFA was responsible for Appendix D and contributed to Appendix G.

David M. Jenkins had overall responsibility for BCL's contributions to the report. T.S. Reddy of BCL drafted Appendices B, F and H. Karen St. John of BCL drafted Appendix C, and Dr. Thomas McClure of BCL contributed to Appendix A.

Dr. Anthony J. Turhollow, Jr., of CARD performed all runs of the ISU Model reported in Appendices A and E and contributed to the drafting of Appendix A.

Thomas J. Timbario of the Transportation/Fuel Systems Department of Mueller Associates, Inc., Baltimore, Md., along with members of his staff, provided consultation and critiqued all draft reports.

The manuscript was typed by Pamela C. Brockington with assistance from other members of the JFA secretarial staff.

TABLE OF CONTENTS

VOLUME III

TABLE OF CONTENTS (Concluded)

VOLUME III

ABBREVIATIONS

B	billion
Btu	British thermal unit
bbl	barrel
bu	bushel
C	Centigrade
cu ft	cubic foot
cwt	hundred weight (100 lb)
d	distance
DDG	distillers' dark grains
DTE	dry ton equivalent
F	Fahrenheit
gal	gallon
ha	hectare
HHV	higher heating value
hp	high pressure
hr	hour
K	Potassium
kw	kilowatt
kwhr	kilowatthour
lb	pound
lp	low pressure
LPG	liquefied petroleum gas
M	thousand
MLRA	major land resource area
MM	million
N	Nitrogen
P	Phosphorus
psia	pounds per square inch absolute
psig	pounds per square inch gauge
T	trillion
wt	weight
yr	year

BTU CONVERSION FACTORS

Fuel	Units	HHV
Coal	Btu/ton	22,500,000[a]
Distillate	Btu/gal	140,000
Electricity Consumption	Btu/kwhr	3,413
Ethanol	Btu/gal	84,200
LPG	Btu/gal	95,000
Lubricating Oil	Btu/gal	145,000
Methanol	Btu/gal	64,350
Motor Gasoline	Btu/gal	125,000
Natural Gas	Btu/cu ft	1,020
Residual Fuel Oil	Btu/gal	150,000

ELECTRICITY CONVERSION FACTOR

Fuel	Btu's consumed/Btu electricity produced
Coal	3.05

[a] *When no specific coal characteristics were known, the energy content of a "standard ton" of coal (22,500,000 Btu) was used. Other values were used when more appropriate and are indicated in footnotes.*

SI CONVERSION FACTORS

1 acre	=	4046.8564 square meters
1 bbl	=	158.98284 liters
1 Btu	=	1054.35 joules
1 cu ft	=	0.028316847 cubic meters
1 gal	=	3.7854118 liters
1 lb	=	453.592 grams
1 mile	=	1609.344 meters
1 psi	=	0.0680460 atmospheres
1 ton	=	907184.74 grams
273.15 + 5/9(F-32)	=	degrees Kelvin
273.15 + C	=	degrees Kelvin

OTHER CONVERSION FACTORS

1 acre	=	0.40468564 ha
1 bbl	=	42 gal
1 Btu	=	252 calories
1 bu barley	=	48 lb
1 bu corn	=	56 lb
1 bu grain sorghum	=	56 lb
1 bu oats	=	32 lb
1 bu soybeans	=	60 lb
1 bu wheat	=	60 lb
1 psi	=	6895 pascals
1 square mile	=	640 acres
1 ton	=	2000 lb

APPENDIX C

FOREST RESIDUES

The high Btu content and clean-burning properties of wood make it an attractive energy source. Forest residues, because of their inherent unsuitability for other uses, are particularly well-suited to be consumed for their energy content, assuming that the engineering and economic constraints are not prohibitive.

The forest products industry is currently the largest user of forest residues for fuel. Within the industry, the pulp and paper sector utilizes 92 percent of total wood energy consumed and has conducted much of the research on using wood residues for energy (Zerbe, 1978)[1].

But despite the value of wood as a fuel, a large volume of wood fiber (1.6 billion cubic feet in 1970) is left in U.S. forests as residue from harvest operations (U.S. Forest Service, 1974). Pre-commercial cuttings, understory removal, and annual mortality are included in this estimate. These residues could be collected during normal harvesting operations using conventional harvesting equipment. They would be well-suited for conversion to methanol.

In this appendix, estimates are developed of the amount of fuel that would be consumed in the collection of forest residues, by harvest system type and by logging operation. Separate estimates are developed for both the Eastern and Western regions of the United States. The appendix concludes with a discussion of the availability of both forest residues and mill residues.

C.1 Selection of Harvest Systems

There are three types of harvest systems used in U.S. forests: a commercial timber harvest, a commercial thin, and a stand improvement thin. In each of these systems, all or portions of a tree may be available for conversion to alcohol. Any harvested wood could be cut into half-inch diameter chips usable as feedstock for alcohol conversion processes. Definitions of each of the harvest systems are provided below.

---

[1] *Parenthetical references to authors and dates identify bibliographic references. Full citations are contained in the bibliography at the end of this volume.*

Commercial Timber Harvest and Commercial Thin. A commercial harvest or thin is the harvest of timber for sawlogs, pulpwood, and/or veneer logs. In a commercial harvest, an entire area is cleared of trees. In a commercial thin, only selected trees are cut for sale or consumption. Only 2.5 percent of commercial forest land is subject to commercial thins (OTA, 1980).

Most forest products manufacturing operations require just a portion of the tree, specifically the stem, or "merchantable bole," for use as raw material. It is that portion of the stem, four inches or more in diameter, that is of commercial value (Howlett and Gomache, 1977). The tree is initially cut at the base above ground (very little whole-tree pulling of stumps and roots is employed), and then the entire tree is transported (skidded) from the felling site to a landing. There the tops and branches are removed (delimbing) and left behind.

An average of 35 percent of the above-ground tree weight represents residue (15 percent in bark; 20 percent in foliage, tops, and branches) (Howlett and Gomache, 1977). After harvesting, the foliage, tops, and branches could be chipped into smaller pieces either at the landing site or at the plant.

Stand Improvement Thin. Stand improvement thinning (i.e., the selective removal of small or inferior trees) is practiced by foresters seeking to improve conditions for growing commercial stock. Currently, only 1.8 percent of commercial forest lands are treated with timber stand improvement practices (OTA, 1980). On these lands, additional growing space is created for higher quality trees by removing those which are dead, diseased or of lower quality. Typically, 40 percent of a stand will be cut, skidded to a landing, and then chipped. The increased availability of sunlight, water, and nutrients allows for more rapid growth of the remaining trees and, thus, leads to increased biomass production.

C.2 Selection of Sites

After consultation with foresters across the country, two regions were selected for analysis: the West (Arizona, Western Alaska, Western South Dakota, Nevada, New Mexico, Utah, Montana, Idaho, Colorado, Wyoming, Oregon, Washington, Northern California), and the East (forested areas east of the Dakotas). The energy consumed in harvest operations will vary somewhat by terrain, tree species, soil type, slope, stem

diameter, other environmental conditions, and equipment operating efficiencies. Unfortunately, detailed energy consumption data are not kept by most forest industry companies. Typically, the only records available are total annual fuel consumed and total annual tons, cords, or cubic feet harvested. The state of the art in forestry record keeping does not provide or permit a detailed breakdown.

Within the two large regions, differences in energy input requirements arise from the utilization of different equipment for different terrains. The major differences occur in the equipment and methods used in the skidding function. In the East, skidders are used to move trees from the felling site to a landing. Cable yarders are used in the West, where slopes exceed 30 percent.

C.3 Energy Consumption Estimates

This section discusses the methods and data used to estimate energy inputs to the collection of forest residues.

C.3.1 Literature Review

Although much information is available on forest residues as an energy source, little hard data exist on the energy consumed in the field. A number of U.S. Forest Service Experiment Stations around the country were contacted for information on forest operation requirements. The Northwest Experiment Station and the Northcentral Experiment Station were the only two Forest Service Stations that have conducted detailed energy analyses on the harvesting of residues. However, the American Pulpwood Association (APA) surveyed member operations in 1975 to determine the fuel consumed in typical harvesting operations. The data developed were average figures for the South, the Northeast and the Lake States. In addition, the Southwide Energy Committee has published information on petroleum product consumption in systems used for energy wood harvesting in the South. To fill in the gaps and improve on these data sources, harvesting managers, equipment manufacturers, private logging contractors, and forest product companies throughout the country were contacted to obtain information on harvesting operations.

C.3.2 Elements of the Net Energy Balance

The three different harvesting systems (commercial harvest, commercial thin, and stand improvement thin) were analyzed in order to determine the energy required to obtain forest residues. Energy inputs were assessed for the specific operations and equipment types within each harvest system. For the commercial harvest and commercial thin systems, only those operations required for obtaining residues were counted in the energy analysis. That part of the forest operation attributable to obtaining sawlogs was not included (i.e., felling, skidding, and delimbing in the East, and felling, cable yarding, and delimbing in the West). For stand improvement thins, the energy used in harvesting the tree was counted in the energy analysis.

The primary energy consuming elements of each of the three harvest systems are:

Harvesting. This includes felling of the tree, transport of the entire tree from the felling site to a landing, delimbing of tops and branches at the landing, and loading onto a truck. In the East, manual systems are used just as extensively as mechanized systems. For felling and delimbing, manual systems use chain saws; mechanized systems use feller-bunchers and mechanical slashers. For the most part, manual systems are also used in the West. In the East, transporting the wood to the landing is done by skidders. In the West, cable yarders are used because the land is generally steeper. A description of the equipment follows (Corcoran, 1976):

- Chain Saw: A portable, gasoline powered, manually controlled machine with a toothed chain used to fell trees and remove limbs.

- Feller-Buncher: A mobile machine that holds a tree by means of a clamp and cutting head, shears it at the stump, then swings and deposits the tree onto a pile on the ground.

- Cable Yarder: A cable hauling system used in transporting trees from the felling site to a landing under steep conditions. The system consists of a hoist with two or more winches powered by an internal combustion engine. Wire ropes are wound along the winches and spun up a tower. The wire ropes are cabled across the skyline. A carriage equipped with hooks travels along this wire. A log is

then hooked and lifted up, enabling it to be cabled back along the wires to a landing.

- Skidder: A tractor unit equipped with a winch or grapple that gathers and skids loads of full trees, tree length boles or logs behind itself from the stump area to a roadside landing.

- Loader: A hydraulically operated boom and grapple used to gather logs or tree lengths for loading onto a truck.

Chipping. Chipping entails feeding the stems and branches resulting from a commercial harvest of thin or whole trees, or from a stand improvement thin operation, into a chipper unit. In Eastern operations, the wood is either chipped and blown into storage piles which are later loaded into vans, or the chips are blown directly into vans. These vans then transport the green wood chips to the plant. In Western operations, chipping usually occurs at the plant because it is more economical to load the large diameter trees onto trucks for transport.

- Chipper: A machine that cuts logs and tree-length wood to small chips of a 1/2 inch diameter by means of a rotating drum or disc, carrying a series of blades. The chips leave the cutting device (in an air-stream induced by the fan effect of the chipping mechanism) and are automatically conveyed into transport vehicles or stockpiles.

Transportation from Harvest Site to Plant. Wood is hauled by truck over an average 100-mile round trip for both Eastern and Western operations with a full load of 19.13 tons.

Miscellaneous Activities. This includes energy consumed in crew transport, maintenance vehicles, repair equipment, and supervision.

C.3.3 Assumptions

Differences in energy consumption were not determined for softwood stands versus hardwood stands. Data found in a study that estimated total energy production and consumption for these types of stands show that the differences are minimal and would not justify a breakdown of this nature (Pimentel, 1980). For this analysis, a mixed hardwood-softwood stand is assumed generating an average of 7.5 dry tons of residues per acre for the East (282 cu ft/acre) and 14.4 dry tons of residues per acre for the West (2,248 cu ft/acre) (Howlett and Gamache, 1977). Thus, to generate the 2,000 dry tons of residues per day required by the conversion facility, 267 acres must be harvested in the East and 139 acres in the West.

The energy expended in the manufacture of the various pieces of equipment is not included in the energy inputs. Only the fuel consumed in operating the equipment while harvesting and transporting wood to the plant is considered.

Manual labor is not taken into consideration nor are any other factors required to produce a ton of dry wood. Chipping and chainsaw requirements are assumed not to differ between regions (Bulkholder, 1981) or harvest methods (Corcoran, 1977). This is also true for the fuel consumed per ton-mile in trucking residues to the plant.

Data provided as units per green ton were assumed at 50 percent moisture content. Data provided as cords presented a problem: a cord of wood is a volume measure of 128 cu ft of piled round wood that can differ in dry weight from about 1,900 lb to 3,500 lb (Smith and Corcoran, 1976). An average 1.5 DTE per cord (Smith and Corcoran, 1976) was used whenever data were provided in units per cord.

The energy used to fell, delimb, and transport trees to a landing in a commercial harvest or thin is assigned to the commercial wood. The practice of stand improvement thinning, however, presents a more difficult problem in the assignment of energy costs. At present, stand improvement thinning for the purpose of improving the growing conditions for the more merchantable trees is performed on only a limited number of acres of commercial forest land (1.8 percent of the total). Dead trees, or those otherwise unacceptable for use as sawlogs or in the production of paper products, are

felled and skidded out of the woods so that they do not impede the harvest of the commercially acceptable trees.

However, when the unacceptable trees are thinned out to allow the commercially usable trees to flourish, the energy consumed in felling and skidding the dead trees must be assigned to harvesting the commercial trees and not to the energy costs of using the thinned out wood for methanol production or some other use. If the dead or commercially poor trees are removed specifically for their use as fuel, for particle board fabrication, or as a forest residue feedstock for methanol production, then it would be valid to assign the energy costs in thinning to that specific end use.

Our analysis of stand improvement thinning as a feedstock source for methanol conversion includes the energy consumed in felling and skidding the unacceptable or dead trees based on the assumption that thinning is not practiced to improve the in-woods growing conditions (though this would be a beneficial side effect). In those cases where the economic value of the thinned out wood and improving the growing conditions for the remaining commercial trees motivates the decision to thin, then the energy costs should properly be shared between inputs to harvesting the commercial trees and using the thinned wood. Where foresters only thin to improve in-woods growing conditions, the energy consumed in thinning should only be assigned to harvesting the commercial trees.

C.3.4 Energy Input Estimates

The energy input estimates calculated for the collection of forest residues by harvest system, by operation, and by region are presented in Exhibit C-1 and Exhibit C-2. Exhibit C-3 provides a summary table of energy consumed in all the systems. Amounts are expressed in Btu's per dry ton equivalent (DTE) and in gallons per DTE. Diesel fuel is the primary fuel for all equipment except chainsaws, which are powered by gasoline.

Since both are widely used, manual systems and mechanized systems are included in data shown for stand improvement thins in the East. Only manual systems are considered for the West due to complications that arise using mechanized systems on steep slopes.

Assumptions and data sources are listed with the tables. Where more than one data source is used for a particular operation, an average number is calculated.

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	1 cord green wood = 1.5 DTE							
	7.5 dry tons forest residues generated per acre (828 cubic feet per acre) (2)							
• COMMERCIAL THIN OR COMMERCIAL HARVEST								
— Chipping	Chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{\text{0.2361 gal of diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{\text{0.1902 gal of diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
TOTAL	COMMERCIAL THIN OR HARVEST		2.83				396,460	396,460

Sources

(1) APA, 1975.
(2) Howlett and Gomache, 1979.
(3) Burkholder, personal communication, 1981.
(4) Tillman, 1978.
(5) Smith and Corcoran, 1976.
(6) U.S. Forest Service - PNW Experiment Station, 1980.
(7) Knapton, 1981.
(8) U.S. Forest Service — NC Experiment Station, 1978.
(9) Southwide Energy Committee, 1980.

*Includes the following states: ME, NH, VT, MA, CT, RI, DE, MD, NJ, NY, PA, WV, MI, ND, SD (east), WI, IL, IN, IA, KS, KY, MN, MD, NB, OH, NC, SC, VA, FL, GA, AL, MS, TN, AR, LA, OK, TX

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Manual System								
— Felling	Trees felled by chainsaws used at the stump — chainsaw energy requirements: (5),(1),(9)	0.286					35,750	35,750
— Skidding	1,831 feet = skidding distance (1) — skidder energy requirements: (4),(5),(1)		0.622				87,080	87,080
— Delimbing	Trees delimbed at landing with chainsaws — chainsaw energy requirements: (5),(1),(9)	0.281					35,125	35,125
— Chipping	Trees chipped at landing — chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Miscellaneous	Crew transport, supervision, maintenance		0.40				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MANUAL SYSTEM	0.57	3.85				610,415	610,415

Sources

See the first page of this exhibit.

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Mechanized System								
— Felling	Trees felled by feller-buncher — feller-buncher energy requirements: (1),(5),(8),(9)		0.436				61,040	61,040
— Skidding	1,831 feet = skidding distance (1) — skidder energy requirements: (1),(4),(5),(9)		0.622				87,080	87,080
— Delimbing	Trees delimbed by a mechanized slasher unit — slasher energy requirements: (1)		0.580				81,200	81,200
— Chipping	Trees chipped at landing — chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{\text{0.2361 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{\text{0.1902 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Miscellaneous	Crew transport, supervision, maintenance		0.40				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MECHANIZED SYSTEM		4.87				681,780	681,780

Sources

See the first page of this exhibit.

EXHIBIT C-2: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE WESTERN UNITED STATES*

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	1 cord green wood = 1.5 tons							
	14.4 dry tons forest residues generated per acre (2,248 cubic feet per acre) (2)							
• COMMERCIAL THIN OR COMMERCIAL HARVEST OPERATION								
— Loading	Knuckleboom loader loads sawlogs onto trucks — energy requirements: (5)		0.342				47,880	47,880
— Transportation by Truck	50 miles full x $\frac{\text{0.2361 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{\text{0.1902 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Unloading	Knuckleboom loader unloads sawlogs from (5) truck		0.342				47,880	47,880
— Chipping	Wood chipped at the plant — chipper energy requirements: (1),(2),(3),(4),(5),(6)		0.609				85,260	85,260
TOTAL	COMMERCIAL THIN OR HARVEST		3.51				492,220	492,220

Sources

(1) APA, 1975.
(2) Howlett and Gomache, 1979.
(3) Burkholder, personal communication, 1978.
(4) Tillman, 1978.
(5) Smith and Corcoran, 1976.
(6) U.S. Forest Service — PNW Experiment Station, 1980.
(7) Knapton, 1981
(8) Southwide Energy Committee, 1980.
(9) U.S. Forest Service — NC Experiment Station, 1978.
(10) Linda Ferguson, John Mandzak, and Max Ekenburg, personal communications, 1981.
(11) Linda Ferguson, personal communication, 1981.

*Includes the following states: AK (coastal), OR, WA, CA, ID, MT, SD (west), WY, AZ, CO, NM, NV, UT

EXHIBIT C-2: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE WESTERN UNITED STATES*

(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Manual System								
— Felling	Trees felled by chainsaws at the stump - energy requirements: (1),(5),(8)	0.286					35,750	35,750
— Yarding	Cable-yarders skid trees to landing site — 1831 feet = skidding distance — energy requirements: (11)		0.507				70,980	70,980
— Delimbing	Trees delimbed at landing with chainsaws — energy requirements: (1),(5),(8)	0.281					35,125	35,125
— Loading	Knuckleboom loader loads sawlogs onto trucks — energy requirements: (5)		0.342				47,880	47,880
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Unloading	Knuckleboom loader unloads sawlogs at plant (5)		0.342				47,880	47,880
— Chipping	Sawlogs chipped at plant (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Miscellaneous	Crew transport, supervision, maintenance		0.400				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MANUAL SYSTEM	0.57	4.42				690,075	690,075

Sources

See the first page of this exhibit.

EXHIBIT C-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES: SUMMARY OF ALL SYSTEMS

		Petroleum Products						
Region	Operation	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• EASTERN UNITED STATES	— Commercial Thin or Commercial Harvest		2.83				396,460	396,460
	— Stand Improvement Thin: Manual System	0.57	3.85				610,415	610,415
	— Stand Improvement Thin: Mechanized System		4.87				681,780	681,780
• WESTERN UNITED STATES	— Commerical Thin or Commercial Harvest		3.51				492,220	492,220
	— Stand Improvement Thin: Manual System	0.57	4.42				690,075	690,075

Specific Inputs. Transportation is by far the largest energy consuming element in the process of collecting residues for alcohol feedstock. The importance of this element can be seen in each harvest system energy analysis, as presented in Exhibits C-1 and C-2.

Chipping is the only other significant energy consuming operation for commercial cuts. Regional differences in energy consumption for chipping result from the way residues are collected. The additional energy required to load and unload stems and trees for Western commercial harvest systems causes the energy differences between East and West. Western forest product companies are currently experimenting with chippers on site. If the use of in-woods chipper units increases in the future, the differences between the two regions could disappear.

The combined operations of transporting wood from the felling site to the landing and chipping the residues account for a significant portion of the energy costs for stand improvement thins. For manual systems in the East, approximately 32 percent of total inputs is consumed by skidders and chippers. In a mechanized system, the equipment consumes 28 percent of the total energy. Cable yarders and chippers account for approximately 25 percent of the total energy consumed for manual thin operations in the West. These figures would only change by 2.5 to 3.0 percentage points if either the lowest energy consumption in chipping figure reported was used (65,500 Btu per DTE reported by Tillman, 1978) or the highest consumption figure was used (104,000 Btu per DTE reported by U.S. Forest Service — PNW, 1980). The change in these percentage figures would be negligible for skidders since data reported were very consistent.

Mechanized harvesting systems require 10 percent more energy than manual systems. This is due to the fuel needed to power mechanized slashers and feller-bunchers.

C.3.5 Possibilities For Reduced Energy Consumption

It is expected that the figures represented in the tables will decrease in the future due to the implementation of energy-conserving techniques. Forest product companies are promoting and implementing fuel-saving activities such as the matching of optimum engine size (horsepower) with level of operation required for a job, increased maintenance of equipment, and reduction of unnecessary engine idling.

C.4 Potential Availability of Residues

Logging Residues

The amount of logging residues available vary greatly by region (Exhibit C-4). The total above-ground forest residue produced in 1970 was estimated at 83 million DTE (Inman, 1977). Large volumes are produced in the West, particularly in the old-growth forests of Oregon, Washington, and northern California. Timber harvesting in those forests generates large amounts of debris. However, use of this excess material by regional pulp and fiberboard industries has progressed slowly because of the availability of lower cost mill residues from lumber and plywood industries (Quinney, 1975).

The largest volumes of logging residues are generated in the South, but these unused materials are not concentrated in accessible areas (i.e., at any given site, only small volumes are generated) (Quinney, 1975). As a result, these residues are not economical to collect. In addition, the Southern pulp and paper industry is increasing its use of the whole tree which will further limit the availability of residues.

The residues left unused from logging operations in the East can amount to substantial quantities, but in general they are widely scattered and probably could not economically support a methanol conversion facility (Quinney, 1975).

Increased utilization of logging residues depends on two factors. First, the expansion of the pulp and paper industry has increased demand for wood fiber. Therefore, competition may exist in some regions between use of the residues for pulp and use of the residues for energy.

Second, a portion of the logging residues should remain on the forest floor to ensure adequate nutrient replenishment. This amount will differ by tree species, age, and soil. Excessive removal of residues could result in soil-nutrient depletion, thus causing a decline in total biomass production. Nutrients might then be needed in the form of manufactured fertilizers (Hall, 1980).

EXHIBIT C-4: SUMMARY OF LOGGING AND MILLING RESIDUES (BY REGION) IN THE U.S. (10^3 DTE) — 1970[a]

Region[b]	Logging Residues					Mill Residues (Wood and Bark)		Total Unused Residues
	Wood[c]	Bark[d]	Tops and Branches[e]	Stump-Root System[f]	Total	Total	Unused	
Northeast	3,451	608	5,248	9,832	19,139	6,600	2,300	21,439
North Central	2,253	397	5,550	9,554	17,754	6,400	2,100	19,854
Southeast	6,684	1,179	10,152	21,066	39,081	11,400	4,500	43,581
South Central	6,552	1,167	12,560	26,084	46,363	16,700	4,600	50,963
Pacific Northwest	7,249	1,279	9,833	24,467	42,828	27,800	4,200	47,028
Pacific Southwest	1,876	331	2,730	6,729	11,666	8,800	3,300	14,966
Northern Rocky Mountain	1,337	236	2,027	5,125	8,725	6,600	2,100	10,825
Southern Rocky Mountain	351	63	665	1,625	2,704	1,800	1,000	3,704
Total U.S.	29,753	5,260	48,765	104,482	188,260	86,100	24,100	212,360

(a) Source: Hall et al. (1980), data adapted from Inman (1977).

(b) Regions are defined as follows: Northeast - Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania and West Virginia. North Central - Michigan, Minnesota, North Dakota, South Dakota (East), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska and Ohio. Southeast - North Carolina, South Carolina, Virginia, Florida and Georgia. South Central - Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma and Texas. Pacific Northwest - Oregon, Washington and coastal Alaska. Pacific Southwest - California and Hawaii. Northern Rocky Mountain - Idaho, Montana, South Dakota (West) and Wyoming. Southern Rocky Mountain - Arizona, Colorado, Nevada, New Mexico and Utah.

(c) Figures include both growing stock and non-growing stock.

(d) Bark estimated as 15 percent of total weight of wood and bark.

(e) Tops and branches, including foliage, estimated as 15 percent of the sum of: timber harvested (including bark), total residues from growing stock and non-growing stock volume.

(f) Assumes that stump-root systems represent 25 percent of total tree biomass. Includes only stump-root systems of commercial species 5 inches or more in diameter at breast height.

Mill Residues

Total mill residues generated in the U.S. in 1970 were estimated at about 86 million DTE (Exhibit C-4). This figure includes only residues generated in the manufacture of lumber, plywood, and miscellaneous wood products, such as shingles, pilings, and posts. Mill residues can provide a ready source of energy, if available. However, approximately 75 percent of these residues were used for some purpose in 1970. Approximately 56 percent of the residues were used for non-energy products, primarily wood pulp, and the remaining 19 percent were either used as fuel within the forest products industry or sold.

Demands for mill residues are apt to increase rapidly as the forest products industry continues to move towards energy self-sufficiency. In any case, this source is not likely to be available for energy use outside of the forest products industry, except in relatively limited local situations.

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APPENDIX D

SILVICULTURAL BIOMASS FARMS

Energy farms and energy farming represent technologies for expanding the biomass resource "pie" to accommodate the production of alternative energy supplies. Energy production is the primary purpose of these farms: biomass is grown and harvested specifically for its energy content. Biomass crops include trees, corn, sugar cane, sorghum, and ocean kelp. These can either be burned directly as fuel or be converted into various synthetic fuels. In many respects, the energy farm concept is similar to the application of intensive agricultural practices to crops grown for food. Under intensive management systems, energy farm sites are extensively prepared and short-rotation[1] energy crops are planted, fertilized, irrigated, and harvested using methods and equipment that have close analogs in conventional agricultural operations.

As yet, silvicultural energy or biomass farms have not been demonstrated in the U.S. However, other countries, particularly Canada and Sweden, have extensively evaluated and are actively pursuing the application of short-rotation forest harvesting to meet national energy needs. In Sweden, where oil imports account for 70 percent of their total energy supply, a large-scale program is under development to practice short-rotation forestry on as much as five percent of Sweden's total land area (Pettersson, 1980). Canada, with its large biomass production capability per capita (i.e., large productive land mass/small population), has a significant potential for producing biomass for use as either an alcohol feedstock or to generate electricity (Middleton et al., 1976).

A silvicultural biomass farm can be characterized as the planting of selected, rapidly growing hardwood or softwood tree species at close spacings (MITRE, 1977a). The tree crop is harvested at intervals, or rotations, ranging from 2 to 10 years (depending on the species growth characteristics) over the expected lifetime of the farm facility. Short-rotation forestry offers the following advantages for energy farming (MITRE, 1977a; Fege, Inman, and Salo, 1979):

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[1] *Short-rotation refers to the harvesting of crops over short intervals of time, e.g., every 2 to 10 years for trees without replanting. A new rotation refers to a new growth cycle following harvesting, not to a new crop being planted.*

- high yields per unit land area during juvenile growth;
- lower land requirements for a given yield;
- early returns on initial investments;
- labor efficiency through mechanization;
- harvest efficiency, through the application of field crop production practices; and
- the ability to take advantage of cultural and genetic advances quickly.

As conceptualized by MITRE (1977a), intensive crop management practices would be applied on a silvicultural biomass farm. These practices would include fertilization, irrigation, and weed control. A largely mechanized harvest system would be employed to remove the above ground biomass without affecting the sprouting capacity of the stumps and to minimize land damage. Other units would be used to convert, transport, and store a year-round supply of biomass in a form compatible with the selected conversion technology.

Silvicultural biomass farms, because they are managed to maximize energy production, yield substantially more biomass per unit area than conventionally managed forests. Part or all of this difference in production could be devoted to alcohol fuels production without reducing our capacity to meet current and near-term fuel wood and forest products industry needs. The Department of Energy has estimated that 1,480 dry tons of wood per day would be needed to produce 50 million gallons of methanol per year (Segal, 1979). At productivity levels of 5 tons per acre-year, one acre of forest land would produce 460 gallons of methanol. In order to obtain enough methanol for a 10 percent mixture with the 100 billion gallons of gasoline consumed in the United States, some 22 million acres of forest land production would be needed per year. This is 3 percent of the total current forest acreage in the U.S. (740 million acres) (Segal, 1979; OTA, 1980). Approximately 65 percent of all forest land in the U.S. is classified as commercial, i.e., produces at least 20 cubic feet per acre-year (OTA, 1980).

In this appendix, the energy inputs for the growing, harvesting, and processing of wood feedstocks for conversion into alcohol fuels are identified on the basis of a conceptualized operation of a silvicultural biomass farm.

D.1 Selection of Species

The impact silvicultural biomass farms will have as an alternative energy source will vary with biomass productivity, i.e., the annual yield per unit area (MITRE, 1977a). Productivity varies as a function of the species planted, the cultural practices used, and site conditions (i.e., soil characteristics, climate, etc.). Species selection, site management, and to some extent site conditions can be altered, within certain biological limits, in order to meet biomass quantity and quality objectives.

Correct species selection is particularly important. Selection criteria include rapid early growth, ease of establishment and regeneration, wide geographical distribution, and resistance to major insect and fungal pests. Perennials are preferred since they can be harvested almost continually throughout the year, permitting more efficient use of machinery and manpower (although there is some loss in productivity if the harvest occurs throughout the year rather than at the end of the growth season). Hardwoods are preferred due to their ability to coppice (i.e., sprout from stumps). Regeneration through coppicing precludes the need for replanting a new tree crop after each harvest and also makes possible propagation by cloning (Szego et al., 1978). Many of these same species, however, have limited site adaptability. Species-site compatibility, therefore, must be carefully evaluated. Ultimately, the most critical selection criterion is the ability to produce high yields under the conditions specified by site location. Exhibit D-1 lists those hardwood and softwood species considered to be best candidates for use in silvicultural biomass farms and describes the limits of their geographical ranges.

Actual yields for a given species on a given site would depend on stand density and management intensity, but studies across many species indicate that yields of 2 - 12 dry tons equivalent (DTE) per acre per year may now be possible and future yields of 15 - 20 DTE per acre per year are expected (MITRE, 1977a; Fege, Inman, and Salo, 1979). One candidate species in particular, Populus, has been the subject of several productivity studies and, as a result, has been selected as the candidate species for this analysis. (Populus includes eastern and black cottonwoods and various hybrid poplars). Bowersox and Blankenhorn (1979), in their survey of the literature and from their experience with dense plantation cultures, concluded that annual productivity of 2 dry tons/acre could be expected for a wide range of sites and Populus parentages in the northeastern United States. Close to 3 dry tons/acre could be achieved, without fertilizer or irrigation, by carefully selecting optimum sites and parentage stocks best suited to those sites (Bowersox and Blankenhorn, 1979).

EXHIBIT D-1: RANGES OF CANDIDATE SPECIES FOR SILVICULTURAL BIOMASS FARMS

Species	Range
American sycamore	All states east of the Great Plains except Minnesota.
Eucalyptus spp.[1]	Generally frost-free areas of the Southeast and California.
Loblolly pine	Coastal Plain and Piedmont from Delaware and Central Maryland south to Central Florida and west to eastern Texas.
Populus spp.[1]	
Eastern cottonwood	Southern Quebec and Ontario to southeastern North Dakota, south to western Kansas, western Oklahoma, southern Texas, northwestern Florida, and Georgia.
Black cottonwood	South along the Pacific Coast from Kodiak Island and southeastern Alaska to mountains in southern California. Eastward into southwestern Alberta, south-central Montana, central Idaho, northern Utah and Nevada.
Sweetgum	Connecticut southward throughout the East to central Florida and eastern Texas. It is found as far west as Missouri, Arkansas and Oklahoma, and north to southern Illinois.
Tulip-poplar	Throughout the eastern U.S. from southern New England west to Michigan and south to central Florida and Louisiana.
Red alder	Confined to the Pacific Coast region from southeastern Alaska south through Washington, northern Idaho, and western Oregon to Santa Barbara, California.

Source: MITRE, 1977a.

[1]Spp. = Species

States. Close to 3 dry tons/acre could be achieved, without fertilizer or irrigation, by carefully selecting optimum sites and parentage stocks best suited to those sites (Bowersox and Blankenhorn, 1979).

As mentioned above, silvicultural biomass farming can produce successive crops without replanting (at least for a maximum of 10 years). Yields of successive rotations are difficult to predict, but coppice crop yields can be expected to be as large or larger than first rotation yields. The number of sustained yield rotations and the yields that are possible depend on several factors (Bowersox and Blankenhorn, 1979):

(1) initial tree density at planting,
(2) the number of years per rotation, and
(3) the investment in fertilizer and irrigation.

As a rule of thumb, increasing the planting density necessitates a decrease in the rotation length.[1] For Populus, maximum rotation length is believed to be no more than 3 to 5 years for a maximum of 4 to 5 rotations per planting. A possible harvesting strategy of 3 years, 3 years, then 4 years has been suggested for short rotations of Populus (Bowersox and Blankenhorn, 1979).

As yet there are only data for yields from two rotations of Populus. Blankenhorn and Bowersox (1980) report average annual yields for second rotation crops for dense stands of Populus (in the absence of fertilizer and irrigation) of 4 to 5 dry tons per acre per year, which are double the first rotation yields of 2 dry tons per acre per year. Fertilizing and/or irrigating the stand could further increase yields to 5 dry tons per acre per year in the first rotation and up to a maximum of 8 dry tons per acre per year for 3, 4, or more rotations.

To maintain site productivity for several rotations, fertilization and irrigation is necessary (Bowersox and Blankenhorn, 1979). Whole-tree harvesting every 3 to 5 years can deplete upper and lower soil nutrients. These nutrients must be replaced either by the application of fertilizers and/or by returning parts of the tree that have nutrient value (for example, harvesting after leaf fall). Bowersox and Blankenhorn (1979) estimate that fertilization alone could produce a 20 percent increase per year in productivity, irrigation alone a 5 percent increase per year, and fertilization and

[1] *T. Bowersox, personal communication, 1980.*

irrigation together, a 30 percent increase per year. As yet, no side-by-side productivity studies have actually been completed on only fertilized vs. only irrigated vs. fertilized and irrigated dense stands.[1]

D.2 Site Selection

Land availability and suitability operates as the second important controlling factor. Unlike biomass productivity, the availability of land for energy farming can be only partially influenced by changes in technology.[2] Instead, socio-economic factors are far more influential, as they determine the balance between competing land uses (including energy farming) and future trends in the supply and demand for land.

Four criteria have been suggested for designating suitable sites for silvicultural biomass farms (MITRE, 1977c; Szego et al., 1978):

- at least 25 inches of precipitation per year;
- a slope no greater than 30 percent (17 degrees) to allow mechanized crop management;
- arable land, i.e., Soil Conservation Service (SCS) land classes I-IV; and
- areas with a population density less than 300 persons per square mile.

In Section D.5, these criteria are applied towards estimating the potential silvicultural biomass farm resources available for the production of methanol fuels. MITRE's (1977a) analysis indicated that 50 percent of the potentially available land for silvicultural biomass farming was located in the Southeast. Our analysis has therefore been performed for a silvicultural biomass farm on an optimum site (i.e., one which meets all suggested criteria) in the southeastern United States. In cases where MITRE's (1977c) energy input data are used, their data for a site in Louisiana are chosen as representative of the Southeast region.

D.3 Selection of a Management System

The operation and design of a silvicultural biomass farm is affected by the feedstock demands of the conversion technology. In this case, the desired feedstock is green wood

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[1] *Ibid.*

[2] *Investments in fertilizer and irrigation can reduce acreage requirements in some instances up to 50 percent (MITRE, 1977d).*

chips less than one inch in diameter. The quantity required for the methanol conversion facility described in Appendix F is 730,000 dry tons per year or 1.4 million green tons per year (assuming a 50 percent wet weight moisture content). At productivity levels of 4 - 12 dry tons per acre-year, these feedstock demands require planting 20,000 - 60,000 acres each year to be harvested after 3 years.[1]

To produce these yields and annual growth levels envisioned for silvicultural biomass farms, it is most likely that intensive management practices, similar to those applied in field crop production, will have to be used. These would include extensive site preparation, mechanized planting, and fertilizing and irrigating the stand. Other options, such as harvesting naturally growing vegetation at a site for its energy value, do not require cultivating, planting, fertilizing, and irrigating the site. However, yields under the so-called "caretaker" system are much less (2 - 3 dry tons per acre-year maximum for Populus). Intensive management offers the opportunity to select high-yielding tree species that are well adapted to a site. These trees can then be planted at a density that facilitates mechanized harvesting and according to a schedule designed to produce a year-round supply of biomass feedstock (Szego et al., 1978). Tree age, size, form, and structure are kept uniform.

For the present analysis, needed planted acreage is calculated on the basis of an average yield of 21 dry tons per acre under intensive management after 3 years growth. This is based on the selection of 7 dry tons per acre per year as the maximum sustainable yield from data presented by Bowersox and Blankenhorn (1979). A total of 107,000 acres is required for the biomass farm at the selected optimum site. Eventually, 105,000 acres will be planted in three 35,000 acre plots to supply 2,000 dry tons per day (730,000 DTE per year). A total of 2,000 acres is assumed to be needed for roads and irrigation lanes (i.e., 2 percent of planted acreage, MITRE, 1977c).

The first step is to clear and prepare the land for planting. This includes clearing the land of its current plant growth (which might be usable as feedstock), tilling the soil, applying fertilizers and lime to correct soil nutrient deficiencies, applying herbicides to control weeds, and building the needed road and irrigation system networks. The next phase is to plant the prepared acreage with seedlings or cuttings of the selected species. These seedlings are grown in nurseries and are planted either manually or by

[1] *Actual total farm acreage would be higher with the addition of needed acreage for irrigation lanes, storage areas, and the needed road network.*

using a mechanized tree planter. Seedlings are planted only in the first year of each 10 year cycle. Successive crops arise by coppicing. How these seedlings are spaced when they are planted, however, is important in determining the growth and productivity of the stand throughout its lifetime. They must be planted close enough to produce a dense canopy of leaves, but not so close that seedlings must compete for light and nutrients. Seedling spacings of 1' x 4', 2' x 4', and 4' x 4' (as measured within and between each row) have been suggested as most productive (U.S. EPA, 1978). This corresponds to 10,900; 5,450; and 2,725 plants per acre, respectively. It is also suggested that plantings be staggered for the initial years of farm operation and over each planting year so that subsequent harvests are also staggered. This is done to provide the desired year-round supply of harvestable biomass feedstock (MITRE, 1977a).

The analysis presumes use of Populus in a 4 foot by 4 foot planting density. Bare root seedlings are planted by mechanized tree planters as the site is prepared. A three-year rotation length is chosen on the basis of Bowersox and Blankenhorn's (1979) data showing a maximum annual growth increment at 3 years for Populus hybrids. A ten year maximum period before replanting each 35,000 acre unit is also established from their data (i.e., 3 crops harvested per planted unit). Herbicides and pesticide applications would also be made, but needed amounts are very much site, species, and situation dependent. Therefore, no amounts have been specified (MITRE, 1977c; Bowersox and Blankenhorn, 1979).

With an intensive system, cultivation after planting includes applying nitrogen, phosphorus, and potassium fertilizers and supplemental irrigation water. How often and how much fertilizer and irrigation water should be applied depends on the site conditions, the species planted, and to some extent, when and how often the trees are harvested.[1]

Since the amount of fertilizer needed depends on the species planted and specific site conditions, it is difficult to generalize to a fertilization scheme (Bowersox and Blankenhorn, 1979). For analysis purposes, it is assumed that each 35,000 acre plot is fertilized:

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[1] *MITRE (1977a) examined 10 possible silvicultural biomass farm sites in the U.S. With the only exception being agricultural land sites in California, needed irrigation amounts were established at an average of one acre-foot per acre per year irrigating over the first three years of each rotation (equal to 6 years in their analysis).*

(a) annually with 89 lb per acre of nitrogen as liquid urea (46 percent nitrogen);

(b) only for the first year of each rotation with 89 lb per acre of potassium as potassium chloride (but normalized as 60 percent K_2O); and

(c) only for the first year of each rotation with 89 lb per acre of phosphorus as concentrated superphosphate (46 percent P_2O_5).[1]

These amounts represent two-thirds the quantities needed for corn crops.[2]

Enough fertilizer for a three year period (10,133 tons of liquid urea; 2,590 tons of potassium chloride; and 3,378 tons of concentrated superphosphate) is assumed to be transported by truck over a distance of 100 miles from a production facility also located in the Southeast region. All fertilizer applications are made during the growing season. Mechanical sprayers are used to apply all fertilizers needed in the first year of each rotation. Nitrogen fertilizer applications for the second and third years of each rotation are combined with applications of irrigation water.

Irrigation water would be applied following a schedule and in amounts compatible with the site's climate and yearly precipitation. Automatic sprinkler (traveller) systems, fogger nozzle systems, flood irrigation, and drip systems have been suggested as possible irrigation systems for silvicultural biomass farms (MITRE, 1977a; Bowersox and Blankenhorn, 1979). For the southeastern site analyzed here, it is assumed that irrigation will be performed at a level of 326,000 gallons of water per acre per year over the 120 day growing season of each year of each rotation (MITRE, 1977c).[3] Precipitation is assumed to provide sufficient moisture for the rest of the year.

A traveller sprinkling system is selected because each unit needed (MITRE, 1977c):

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[1] *Values based on Bowersox and Blankenhorn's (1979) analysis assuming a fertilizer requirement of 200 lb of nitrogen, phosphorus, and potassium for a 10,000 acre farm.*

[2] *T. Bowersox, personal communication, 1980.*

[3] *Irrigation needs would actually have to be established for each site. MITRE (1977c) established these numbers as representative for their 10 sites analyzed (except California) and their numbers have been used here.*

- requires only one man to operate;
- is adaptable to a wide range of field sizes and shapes;
- is easy to transport;
- has a wide range of travel speeds and application rates;
- is capable of a uniform application within a 200-foot watering radius; and
- is adaptable to rolling or irregular topography.

Each traveller system consists of a pump, power unit, main supply pipe, flexible irrigation hose, four-wheeled traveller unit, and sprinkler. Drawing water from one or several main supply pipes, each traveller unit is drawn down the 10 - 12 foot wide irrigation lanes by a cable reeled in from a fixed point. Traveller units are moved around the site by tractors.

The final stage is harvesting the tree crop. This is a highly mechanized process involving equipment specially designed to harvest most of the above-ground biomass, leaving an undamaged stump able to coppice. MITRE (1977c) proposed harvesting during the winter months when the trees are dormant in order to take advantage of the last productive year of growth per rotation and to avoid adversely affecting the regeneration of the next crop. Compared to year-round harvesting, however, shortening the harvesting season to the winter months would require:

- more equipment to harvest the same acreage;
- a year without a harvest with every 10 year replanting cycle since replanting cannot start until spring of the following year;
- additional yields, to compensate for losses in storage;
- on-site storage for stockpiling the harvested feedstock supply until used; and
- 25 percent more fuel for the harvesting equipment, due to the effect of winter operations on fuel consumption (Southwide Energy Committee, 1980).

Therefore, a year-round, staggered planting-harvesting schedule has been assumed. Harvesting of each planted unit is assumed to occur at a rate of 96 acres per day which produces the needed daily yield of 2,000 dry tons. Harvesting operations are based on an 8 hour day, 7-day week, and 52-week year. Since the feedstock is produced at the rate it is used, minimal on-site storage is needed. Replanting each 35,000-acre plot is

assumed to occur as the third coppice crop is harvested. This schedule is depicted in Exhibit D-2. In actual operation, planting operations would have to be compressed to correspond to the planting season. Therefore, harvesting operations for the third coppice crop must be adjusted to compensate.

For any type of woodland operation, several factors are critical to the selection of a harvesting method (Koch, 1980): (a) terrain feature, (b) soil characteristics, (c) weather, (d) stand density, (e) tree diameter distribution, (f) species mix, (g) the scale of the harvesting operation, (h) tract size, and (i) the purpose for which the trees are harvested, i.e., for fuel, pulpwood, wood products, or chemical products. Considering the large tract sizes envisioned for a single species silvicultural biomass farm where stand density is high and the tree diameter distribution is fairly uniform but small (less than 8 inches after 3 to 4 years growth), a whole-tree harvesting system seems best suited for producing the needed quantity and quality of wood feedstock.

There are two types of whole-tree harvesting systems: chipping at the stump and chipping at the landing. Choosing between these systems depends to a large extent on harvesting costs and efficiency. Production rates and harvesting costs are highly dependent on tree diameter (Plummer, 1977). With three to four year rotations for each crop, tree diameters may reach a maximum of 8 inches depending on the species, but probably will average 4 inches or less. This is in contrast to diameters of 12 to 20+ inches after the rotation lengths of 30 or more years common to commercial forestry operations where the trees are harvested for pulpwood or wood products. For a whole-tree chipping system common to pulpwood operations (utilizing feller-bunchers, grapple skidders, and a whole-tree chipper at a landing), the number of cords processed per hour drops dramatically as the tree diameter declines, while the cost per cord increases (Plummer, 1977). Such a system, clearly, would not prove economical for a silvicultural biomass farm operation of the type we have described. Instead, a whole-tree system utilizing a mobile harvesting unit which fells and chips the smaller trees at the stump would seem to be a more economical and efficient harvesting method.

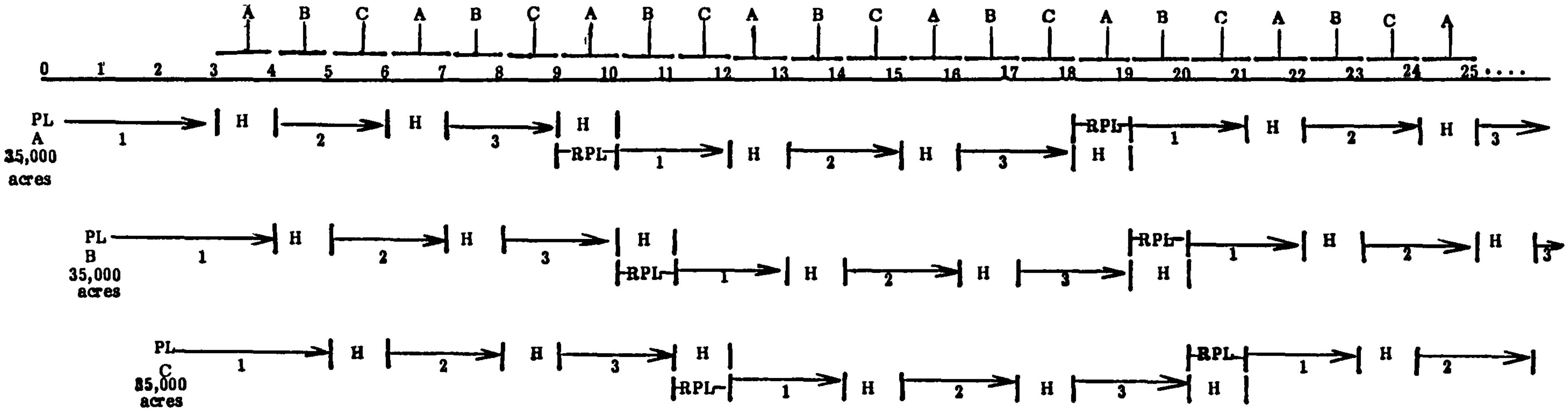
Such a chip-at-stump system has therefore been assumed in the present analysis. Besides being able to produce more tons (or cords) per hour than a chip-at-landing system for trees sized 8 inches or less, a chip-at-stump system also minimizes field traffic and therefore soil disturbance and can be designed to operate at close spacings.

EXHIBIT D-2: PROPOSED PLANTING HARVESTING REPLANTING SCHEDULE FOR A SILVICULTURAL BIOMASS FARM BASED ON A THREE YEAR ROTATION PERIOD, YEAR ROUND HARVESTING, AND A MAXIMUM OF TEN YEARS BEFORE REPLANTING

Total Farm Acreage: 107,000 acres in three 35,000 acre plots
Total Planted Acreage: 105,000 acres

Production: 470,000 green tons/yr., 735,000 dry tons/yr.
Average Yield/Acre After 3 Yrs. Growth: approx. 21 tons/acre

Harvest of 735,000 dry tons/year at a rate of 2,000 dry tons/day from plots A, B, and C (=96 acres per day)



KEY: PL = site preparation and planting
H = harvesting, year round at rate of 96 acres/day
RPL = replanting
1 = first growth
2 = second coppice crop
3 = third coppice crop

Assumes: harvesting each crop after 3 year intervals at a rate of 96 acres/day, 365 days/yr. — after 10 years, each plot is replanted as the third coppice crop is gradually harvested

therefore soil disturbance and can be designed to operate at close spacings. The number of harvester units needed is estimated to be 23 on the basis of the following equation derived by MITRE (1977c):

$$\text{units needed} = C \times \frac{P_a}{MAI \times R \times S \times W \times HPS \times FE \times LE}$$

where:

C	=	8.25, the reciprocal of 0.1212, the number of acres in a swath one foot wide and one mile long
P_a	=	annual production = 730,000 DTE per year
MAI	=	mean annual growth increment = 7 DTE per acre per year
R	=	rotation length = 3 years
S	=	harvester speed = 1 mph (Koch, 1980)
W	=	swath width = 8 feet (2 rows at 4 ft spacing)
HPS	=	working hours per harvest season = 2,920 hours
FE	=	field efficiency = 0.60
LE	=	labor efficiency = 0.09

(Note: MAI, S, HPS, and FE are all site dependent)

This figure agrees with calculated equipment needs of 20 - 24 mobile harvesters estimated from reported production capacities for first generation harvesters of 12 - 15 dry tons of biomass per hour (96 - 120 tons per 8 hour shift) (Koch, 1980). Unfortunately, only a few mobile harvester/chipper units have been built and tested under field conditions. None of these field conditions have corresponded to dense, short-rotation plantations (Koch, 1980).[1] As a result, data on fuel consumption rates and production rates are limited. This will change with further testing, but, for the time being, this limited data must be supplemented with fuel consumption figures for a chip-at-landing system.

These mobile harvesters cut and chip the whole trees and blow these chips into trailing chip forwarder vehicles. Two, 10-ton capacity, quick-dump chip forwarders are

[1] *J. Odair, personal communication, 1980.*

harvester units, 46 forwarders would be needed to transport chips to temporary storage areas at the gasification plant.

The wood gasification plant is assumed to be located at the center of the surrounding 107,000-acre silvicultural biomass farm site. This minimizes feedstock transportation costs. The average, one-way, harvesting-site-to-plant transportation distance is calculated to be 5 miles.[1] Alternative plant site locations would necessitate the use of highway tractor-trailers to transport the wood chips to the gasification plant.

Other process components include feedstock storage and drying. Storage areas can be located at several places on the farm site or on the gasification plant site. In this analysis, storage and feedstock drying take place at the gasification facility.

Finally, labor is used throughout, particularly during the land preparation and planting stages (although the energy used in labor is not considered in this analysis). Overall, less labor is needed for a silvicultural biomass farm than for a conventional forestry operation. Also included in the operation of a biomass farm (but not considered as energy inputs) are such miscellaneous operations as planning, supervision, maintenance, field support/supply, and crew transport. The biomass farm described above forms the basis for evaluating energy inputs in the next subsection.

D.4 Energy Consumption Estimates

Exhibit D-3 illustrates the elements of an intensively managed biomass production system which involve or influence energy consumption. In estimating the petroleum and nonrenewable fuel inputs to silvicultural biomass farm operations, this analysis has distinguished between "primary" and "secondary" inputs. The tables that follow present consumption estimates for all primary inputs (the fuels consumed by the equipment used in each operation) and for the major secondary inputs (the fuels consumed in the manufacture of fertilizers). Labor inputs and energy consumed in the manufacture of the equipment used are not included in the analysis .

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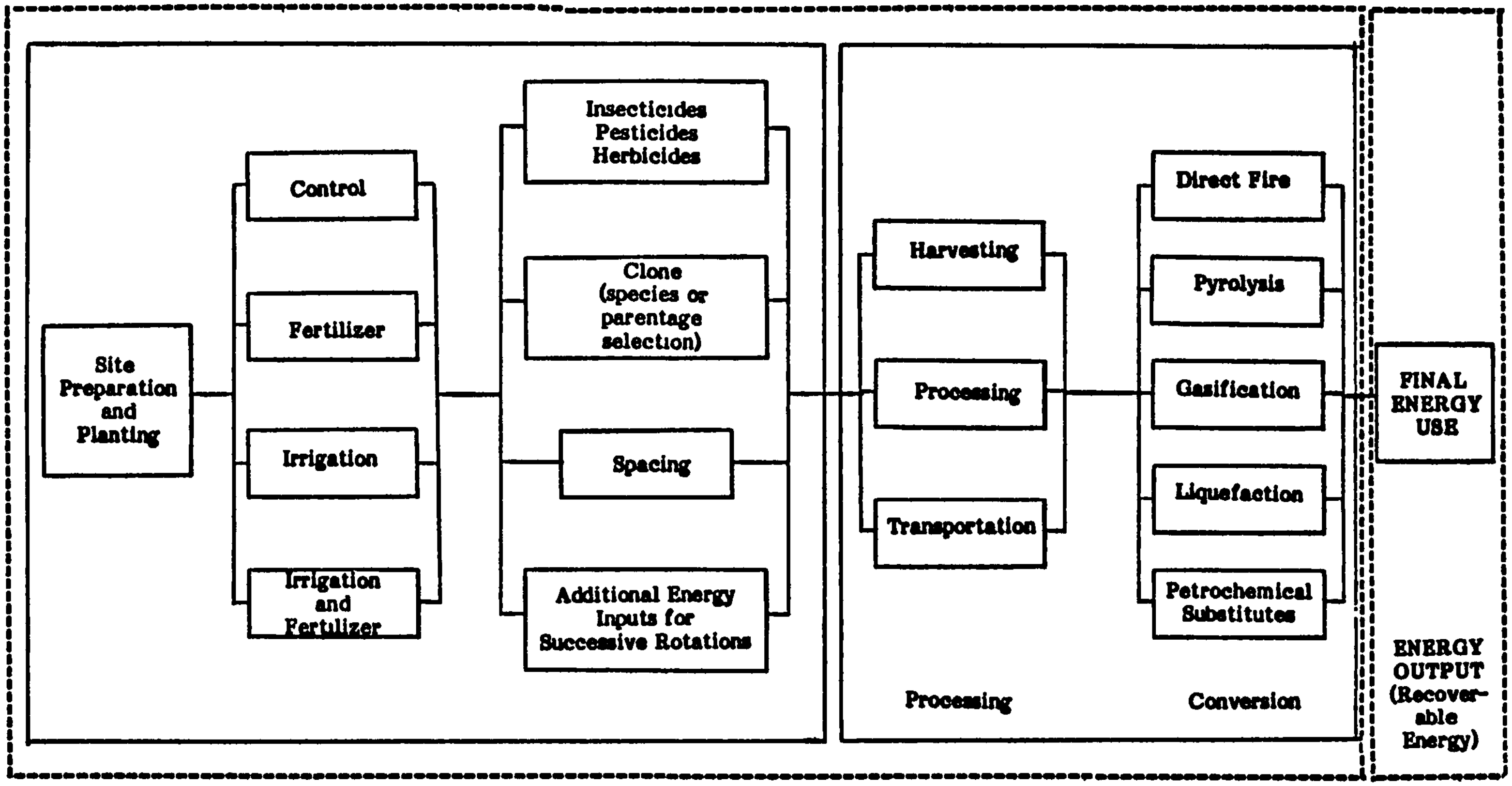
[1] *If the 107,000 acre biomass farm site is seen as a circular area, the average distance from all points within that area is two-thirds of the radius r.*

EXHIBIT D-3: ELEMENTS OF AN INTENSIVELY MANAGED SILVICULTURAL BIOMASS FARM



Adapted from: Bowersox and Blankenhorn, 1979.

D.4.1. Literature Review

A search conducted of the current literature for estimates of energy inputs in biomass farm operations revealed two types of data sources. The first type was fuel consumption data for harvesting wood for pulp and paper use, such as the 1975 American Pulpwood Association (APA) fuel use survey and reports from the Southwide Energy Committee (SEC) (1980). The APA reported average fuel consumption figures for typical harvesting operations based on surveys of member operations in the South, Northeast, and Lake States. The Southwide Energy Committee presented similar data for pulpwood harvesting operations in the southeastern United States. Supplemented by data from contacts with forest product companies and equipment manufacturers, APA and SEC data have been used for representative fuel consumption rates for silvicultural biomass farm harvesting operations. It should be recognized, however, that wood harvesting operations for pulp and paper uses are not directly comparable to the operation visualized for a silvicultural biomass farm. Harvesting a uniform and dense stand of trees that grow to a maximum of 4 to 8 inches in diameter requires different equipment needs, design, and operation than harvesting widely spaced, 22-inch diameter trees after at least 30 years of growth. These differences were reflected in the biomass harvesting system selected.

Other sources of energy consumption estimates were analyses of conceptualized silvicultural biomass farm designs. The most important of these were a series of MITRE reports and the more recent analyses of Bowersox and Blankenhorn et al. The design and operation of the silvicultural biomass farm analyzed is based on selected elements taken from those reports. MITRE's reports defined the operational characteristics and parameters of a biomass farm and the potential availability for silvicultural biomass farms in the United States. Bowersox and Blankenhorn provided information on sustainable productivity with and without fertilizers and irrigation, maximum rotation lengths, and estimated energy inputs for several proposed silvicultural biomass farm operations.

D.4.2. Energy Input Estimates

Exhibits D-4 and D-5 show primary nonrenewable energy input estimates for the silvicultural biomass farm operations described above. The table that follows this paragraph shows that fertilizing and irrigating the biomass farm site are the two major

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION*

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SITE PREPARATION								
— Land Clearing	Clear land of a natural timber stand with brush growth — growth chipped and burned for process fuel — use gallon per ton consumption figure for a chain saw used in the woods at the stump — (1)	0.13					16,250	16,250
— Tilling and Other Soil Preparation	Medium site preparation using a 200 horsepower shear blade tractor and 150 horsepower root rake tractor — (2)							
	Shear Tractor: 2 acres/hour; 10 gal diesel fuel/hour; 5 gal diesel fuel/acre		0.24				33,600	33,600
	Root Rake Tractor: 1 acre/hour; 7 gal diesel fuel/hour; 7 gal diesel fuel/acre		0.33				46,200	46,200
TOTAL	SITE PREPARATION	0.13	0.57				96,050	96,050

Sources

(1) Southwide Energy Committee, 1980.
(2) Georgia Forestry Commission, 1980.

* Utilization per ton figures shown were calculated on the basis of a final yield of 21 ovendry tons per acre after 3 years of growth producing a total of 735,000 dry tons per year (at a rate of 2,000 dry tons per day) for each 35,000 acre planted unit.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION
(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• PLANTING								
	65 horsepower crawler tractors pulling a medium duty tree planter — (3)							
	1.25 acres/hour 1.75 gal diesel fuel/hour 1.40 gal diesel fuel/acre		0.07				9,800	9,800
TOTAL	PLANTING		0.07				9,800	9,800

Sources

(3) Georgia Forestry Commission, 1980.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION (Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FERTILIZER								
— Manufacture	N applied as liquid urea which is 46 percent nitrogen — apply 89 lb N per acre per year — equals 4673 tons nitrogen over 3 years and 10,133 tons liquid urea — (4)			0.02	361	0.002	2,994	421,214
	K applied as muriate of potassium which is 60 percent K_2O — apply 89 lb K_2O per acre for only the first year of each rotation or 148 lb muriate of potassium per acre equals 1,558 tons K_2O and 2,590 tons muriate of potassium over 3 years — (4)			< .0001	4	0.0004	< .0001	14,080
	P applied as concentrated superphosphate (CSP) which is 46 percent P_2O_5 — apply 89 lb P_2O_5 per acre for only the first year of each rotation or 193 lb CSP per acre — equals 1,558 tons P_2O_5 or 3,378 tons CSP over 3 years — (4)	0.0001	0.0005	0.02	21	0.002	3,064	74,484
— Application	Mechnical sprayer used to apply fertilizers needed in first year of each rotation only — fertilizers all applied at once — uses 0.25 gal diesel fuel per acre — (5) — due to density of stand in second and third years of the rotation, sprayers cannot be used — applied as mixture with irrigation water		0.01				1,400	1,400

Sources

(4) Bowersox and Blankenhorn, 1979; MITRE, 1977a.
(5) Blankenhorn, Bowersox, and Murphy, 1978.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION (Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FERTILIZER								
— Transportation	Every 3 years need to transport to farm site a total of 16,101 tons of fertilizer — over 3 years apply total of 920 lb fertilizer/acre Liquid urea: 10,133 tons Potassium Chloride: 2,590 tons CSP: 3,378 tons Transporting chemical and allied products by truck involves an energy input of 2,830 Btu's diesel fuel per ton-mile with an average load of 18 tons — assume fertilizer transported a distance of 100 miles		0.04				5,600	5,600
TOTAL	FERTILIZER	0.0001	0.051	0.04	386	0.004	13,058	516,778

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• IRRIGATION								
	Automatic sprinkler (traveller) system to irrigate the stand over a 120 day growing season each year of the rotation							
— Moving the Traveller Unit	0.65×10^9 Btu diesel fuel consumed per year produce 250,000 dry tons per year — (6) — converts to 2,600 Btu's diesel fuel/dry ton		0.02				2,600	2,600
— Traveller Unit Operation	112×10^9 Btu energy consumed per year to produce 250,000 dry tons/year or 448,000 Btu/dry ton — (6) — assume all is diesel fuel		3.2				448,000	448,000
TOTAL	IRRIGATION		3.22				450,600	450,600

Source

(6) MITRE, 1977c.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION (Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• HARVESTING AND CHIPPING								
	Mobile harvester/chipper consumes 15 gal diesel fuel per hour, operates 8 hours per day, 365 days per year to harvest 96 acres/day — equals 1.25 gal diesel fuel/acre		0.06				8,400	8,400
TOTAL	HARVESTING AND CHIPPING		0.06				8,400	8,400

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION (Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FORWARDING OF WOOD CHIPS								
	Chip forwarder trailing harvester/chipper consumes 2.4 gal diesel fuel/hour — (7) — operates 6 hours per day, 365 days per year to harvest 96 acres per day — equals 0.15 gal diesel fuel per acre		0.007				980	980
	chip forwarder transporting chips to plant site (8)							
	5 miles full x $\frac{\text{0.50 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{10 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		0.50				70,000	70,000
	5 miles empty x $\frac{\text{0.40 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{10 tons}}$ x $\frac{\text{2 tons green wood}}{\text{acre}}$		0.40				56,000	56,000
TOTAL	FORWARDING		0.91				126,980	126,980

Sources

(7) Southwide Energy Committee, 1980.
(8) APA, 1975.

EXHIBIT D-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK FROM A SILVICULTURAL BIOMASS FARM: SUMMARY OF ALL ENERGY INPUTS

	Petroleum Products						
Energy Consuming Element	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SITE PREPARATION	0.13	0.57				96,050	96,050
• PLANTING		0.07				9,800	9,800
• FERTILIZER							
— Manufacture	0.0001	0.0005	0.04	386	0.004	6,058	509,778
— Transport		0.04				5,600	5,600
— Application		0.01				1,400	1,400
• IRRIGATION		3.2				450,600	450,600
• HARVESTING AND CHIPPING		0.06				8,400	8,400
• FORWARDING		0.91				126,980	126,980
TOTAL ALL ENERGY INPUTS	0.13	4.86	0.04	386	0.004	704,888	1,208,608

energy consuming components of the operational design analyzed, accounting for 43 percent and 37 percent, respectively, of total energy consumed (in Btu per dry ton). In contrast, the energy consumed in either planting or harvesting the tree crop accounts for less than one percent of the total.

Energy Consumed in Each Farm Operation Category

Operation Category	Btu per dry ton of wood	Percent of total
Site Preparation	96,050	7.9
Planting	9,800	0.8
Fertilizer	516,778	42.8
Irrigation	450,600	37.3
Harvesting/Chipping	8,400	0.7
Forwarding	126,980	10.5
TOTAL	1,208,608	100.0

Considering differences in assumptions and design, these results agree well with other analyses of energy inputs to silvicultural biomass farm operations. MITRE (1977c) also considered only primary energy inputs in its analysis, because estimates by Alich and Inman (1974) showed that the energy inputs in equipment manufacture accounted for only a small fraction of total inputs. In MITRE's analysis of a site in Louisiana, total energy expended per dry ton of wood feedstock was calculated to be 1,108,320 Btu (relative to producing 250,000 DTE per year). Of this total, the energy consumed in irrigating the site with a traveller unit accounted for 40 percent. Energy consumed in the manufacture of the fertilizer made up 37 percent of the total energy consumed per dry ton of feedstock. Energy requirements for harvesting were less than 3 percent of the total. The only major difference between our analyses and MITRE's was in the energy consumed in transporting the harvested biomass from field storage to the conversion plant. MITRE (1977c) attributed 6 to 7 percent of the total energy consumed to this operation. The design analyzed in the present study, which assumes that the gasification plant is located at the center of the farm site, minimizes the feedstock transportation distance. Transportation of the feedstock, depending on distance, can represent almost 50 percent of the total energy input (Smith and Corcoran, 1976).

Blankenhorn, Bowersox, and Murphy (1978) also established energy input figures for a conceptualized silvicultural biomass farm operation following a 10-year growth and

harvest cycle. Again, the energy consumed in fertilizer manufacture and application accounted for a significant fraction (67 percent) of the total energy consumed by an intensive system. Fuel energy requirements for site preparation, planting, and harvesting represented 32 percent of the total. Only 0.5 percent of the total energy consumed could be attributed to equipment manufacturing inputs. Irrigation of the site was not included in their analysis.

D.5 Potential Silvicultural Biomass Farm Resources Available

The location of silvicultural biomass farms operation will be influenced by a variety of factors, including the economics of competing land uses, decisions concerning the use and management of national forest lands, and the costs associated with transporting the feedstock to the gasification plant. The only regions of the country where biomass farms would probably not be located are the Mountain States, the Southwest, and California. Actual site selection would require a site-by-site compatibility analysis such as that performed by MITRE (1977c) in selecting ten representative sites.

Location of the gasification plant at the center of the biomass farm site, as assumed in the above analysis, minimizes feedstock transport costs and fuel consumption.

In evaluating land suitable for silvicultural biomass farms, MITRE (1977c) developed six land availability "scenarios." The most likely sources of land for such farms were found to be included in their Scenarios 2 and 3. Scenario 2 consisted of all permanent pasture, forest and range land in Soil Conservation Service (SCS) capability classes I-IV; Scenario 3 consisted of the same lands plus all rotation hay and pasture land, hayland and openland formerly cropped in these four classes. Both scenarios exclude present cropland. The two scenarios contain 270 and 320 million acres, respectively, with nearly half the acreage located in the southeastern United States (Production Regions 2, 3, and 6).

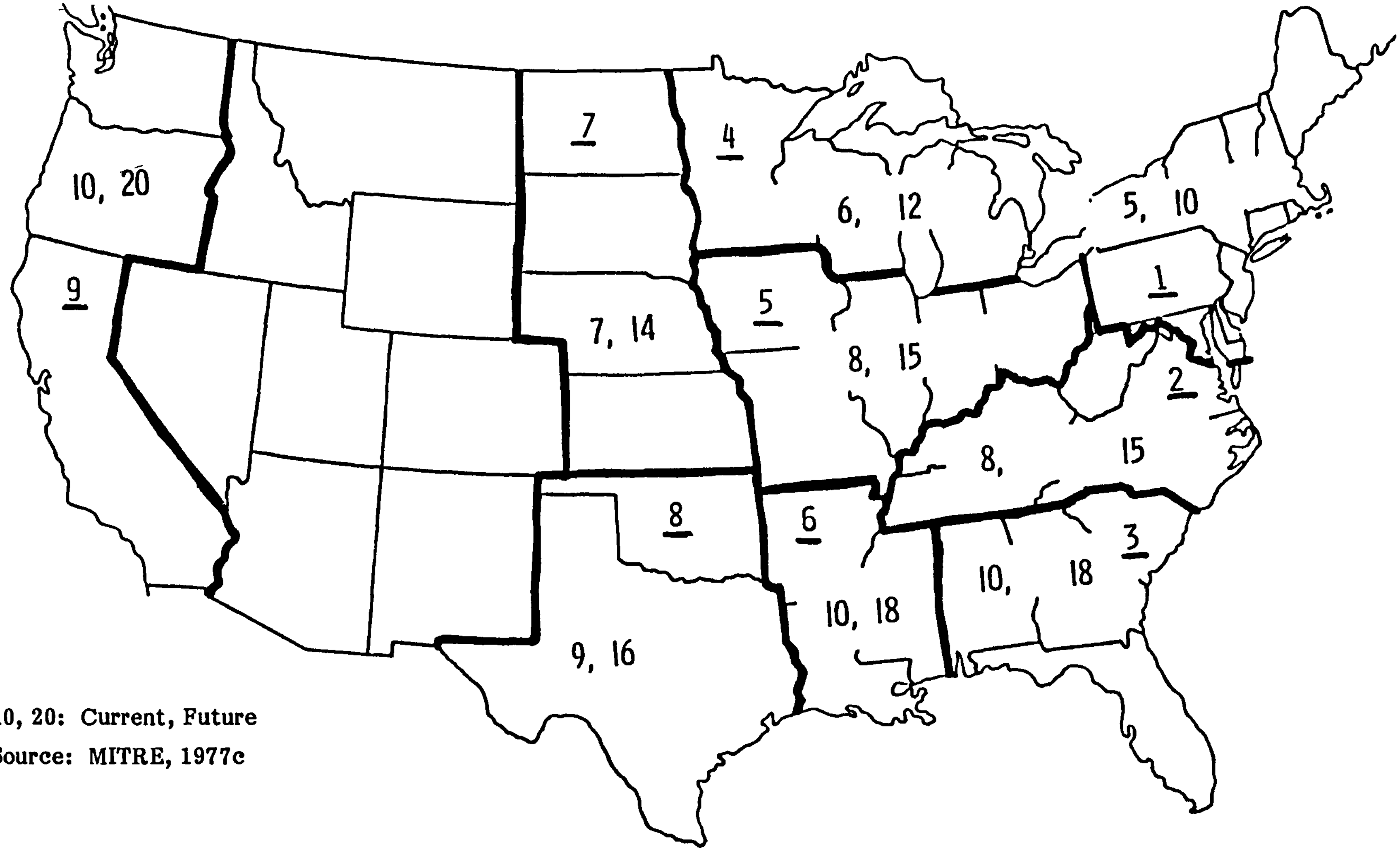
MITRE conservatively estimated that only 10 percent of the total could be devoted to silvicultural biomass farms. Exhibit D-6 summarizes the total land areas available and estimated biomass yields which could be obtained if MITRE's scenarios were followed. Exhibits D-7 through D-9 show the distribution of these land areas and yields across nine United States farm production regions.

EXHIBIT D-6: LAND AREA AND PROJECTED FEEDSTOCK YIELD (IN DRY TONS PER YEAR) FROM 10 PERCENT OF THE AREA IN THE TWO MOST LIKELY LAND AVAILABILITY SCENARIOS FOR SILVICULTURAL BIOMASS FARMS

	Total Land Area Available (millions acres)	Wood Feedstock Yield From 10% of This Total Land Area (millions of dry tons/year)	
		Current	Future
SCENARIO #2 SCS Classes I-IV: Forest, Pasture, Range	268.3		
Production Region			
1	29.0	14.5	29.0
2	36.5	29.2	54.8
3	51.1	51.1	92.0
4	33.5	20.1	40.2
5	28.5	22.8	42.8
6	35.2	35.2	63.4
7	6.5	4.6	9.1
8	42.3	38.1	67.7
9	5.6	5.6	11.2
SCENARIO #3 SCS Classes I-IV: Forest, Pasture, Range Rotation Hay/Pasture Hayland, Open Land Formerly Cropped	324.5		
Production Region			
1	38.0	19.0	38.0
2	43.8	35.0	65.7
3	53.0	53.0	95.4
4	44.9	26.9	53.9
5	44.1	35.3	66.2
6	38.0	38.0	68.4
7	9.1	6.4	12.7
8	46.4	41.8	74.2
9	7.2	7.2	14.4

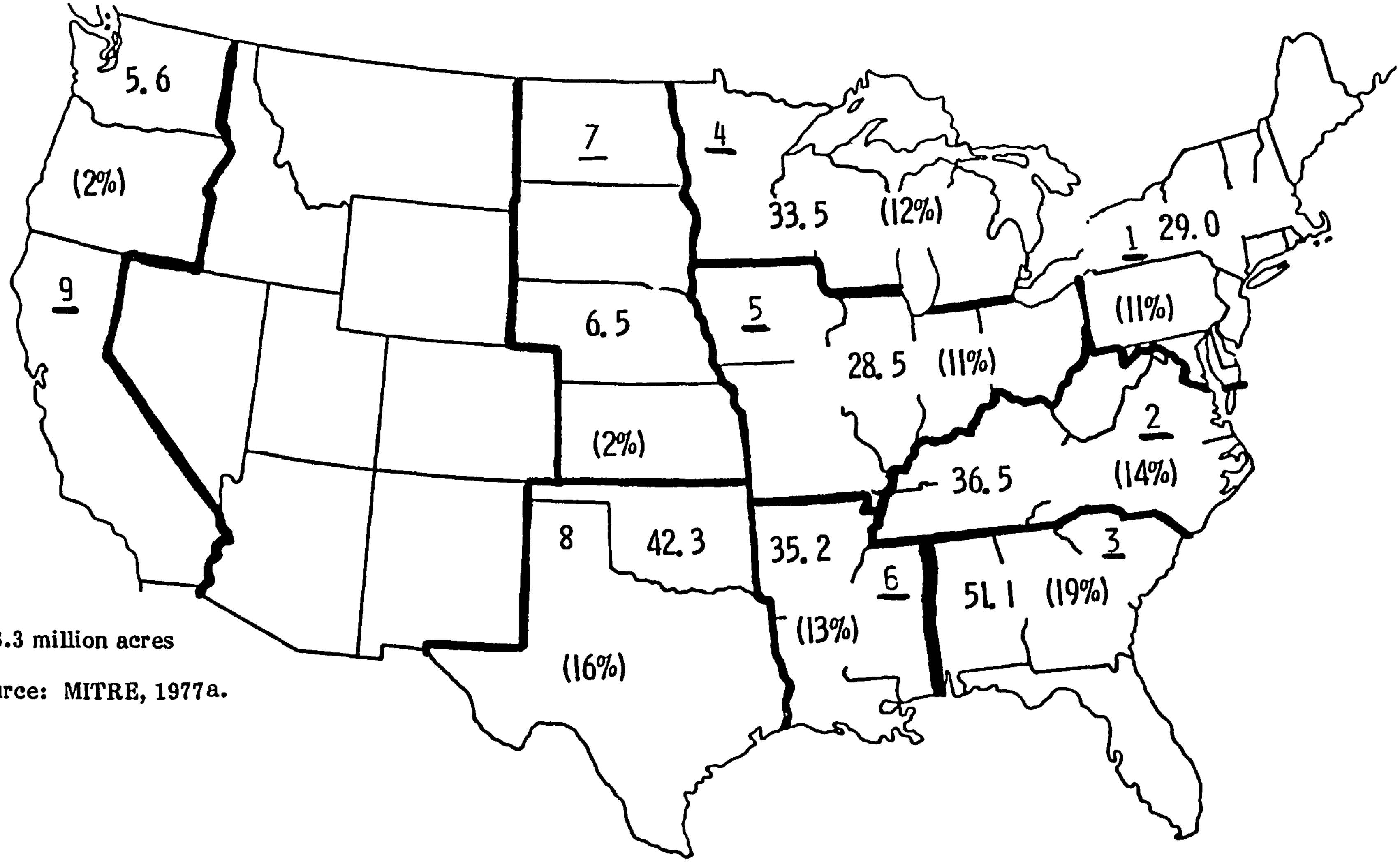
Source: MITRE, 1977c.

EXHIBIT D-7: ESTIMATED CURRENT AND FUTURE BIOMASS YIELDS ON SILVICULTURAL BIOMASS FARMS IN FARM PRODUCTION REGIONS 1-9.
(Dry tons per acre per year)



10, 20: Current, Future
Source: MITRE, 1977c

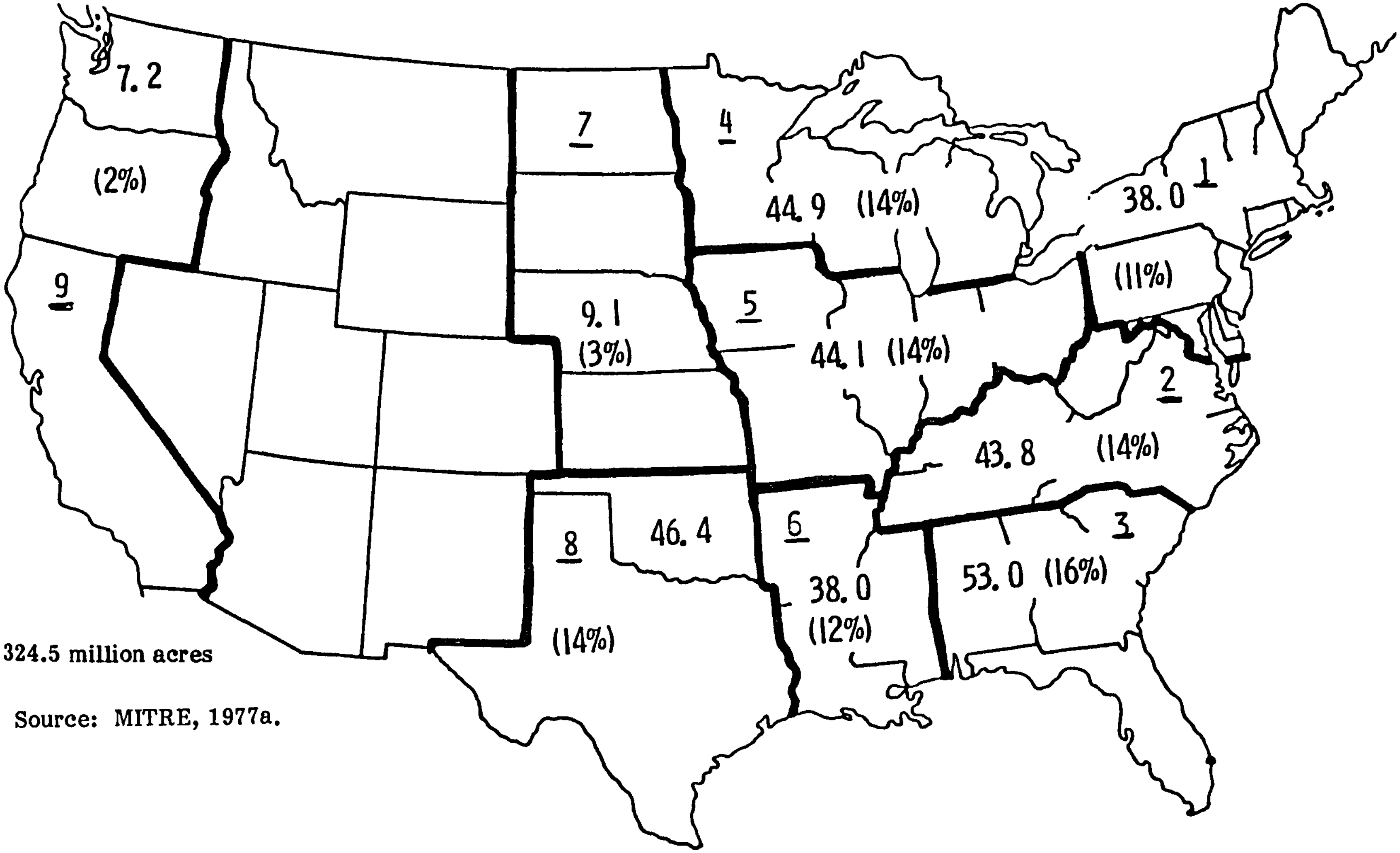
EXHIBIT D-8: DISTRIBUTION OF AVAILABLE LAND IN SCENARIO 2: CLASSES I-IV; FOREST, PASTURE, RANGE Million Acres (% of Total)



268.3 million acres

Source: MITRE, 1977a.

EXHIBIT D-9: DISTRIBUTION OF AVAILABLE LAND IN SCENARIO 3: SCS CLASSES I-IV; FOREST, PASTURE, ROTATION HAY AND PASTURE, HAYLAND, OPEN LAND FORMERLY CROPPED
Million acres (% of Total)



324.5 million acres

Source: MITRE, 1977a.

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Szego et al. (1978) estimated available land for energy plantations at 175 million acres using criteria which excluded

(1) prime cropland, commercial forest, pasture, range and recreational land;

(2) lands west of 101st meridian except for the western slopes of the Pacific coastal mountains (areas receiving less than 20 inches of precipitation per year); and

(3) excluded areas where population density exceeded 300 people per square mile.

Szego et al. (1978) did not apply the assumption that only 10 percent of this total possible land area would be available.

As urban and suburban expansion continues, however, the supply of land available for all other uses including energy farming will decrease. This may be offset somewhat by the increased use of more marginal lands (along with selecting more adaptable, less site demanding species) provided that the investment in more intensive cultivation results in adequate, economical, biomass yields (U.S. EPA, 1978).

APPENDIX E

AGRICULTURAL RESIDUES

Agricultural residues are an interesting potential source of cellulose for methanol conversion. They are a by-product of agricultural production; by definition residues are the parts of the plant other than the grain, seed or fiber for which the plant is grown (Larson, 1979).

Among agricultural residues, the present analysis is limited to field residues; these constitute 94 percent of the organic solids produced annually as crop residues. The other 6 percent are from centralized locations such as cotton mills and sugar refineries (U.S. EPA, 1978). There are no harvesting energy costs associated with the collection of such non-field residues, and, if the residues are used on site, neither are there any transportation eneryg costs.

Although crop residues are often perceived as a waste, they may perform many functions. Crop residues are sometimes used as animal feed and bedding (Larson, 1979); corn cobs may be used in the manufacture of chemicals (U.S. EPA, 1978).

But even when the residues decay in the field, they have a value. Crop residues contain nitrogen, phosphorous, and potassium, as well as other less energy-intensive nutrients. When crop residues are left on the field, most of these nutrients eventually return to the soil. When crop residues are removed, additional fertilizer (which has a significant energy value) must be applied to the soil to maintain the soil nutrients at the level that would otherwise exist in the presence of decaying residues.

Crop residues also provide soil with organic matter, which increases soil fertility and reduces soil density (Robertson and Mokma, 1978). In energy terms, an increase in soil density increases the power required to plow the soil. Organic matter also maintains soil porosity, which permits high rates of water and oxygen infiltration and reduces the quantity of water that must be added to the soil for adequate plant growth. In dry, but as yet nonirrigated areas, this can significantly affect grain production. Even in irrigated areas, the ability of high-porosity soil to hold water may affect energy consumption due to the energy-intensive nature of irrigation.

But more important than the loss of fertilizer nutrients (which can be replaced with manufactured fertilizer) and organic content (which can be replaced with manure) is the increased loss of topsoil (due to wind and water erosion) that results from residue removal. The Soil Conservation Service develops estimates of soil loss tolerance for particular soil types and field depths (U.S. Soil Conservation Service, 1973). At present, average soil loss per acre on cultivated land in the United States is well above the maximum soil loss level per acre at which current productivity can be maintained (Lockeretz, 1980). These conditions exist at a time when residue removal (which can increase soil loss by a factor of two) is only rarely practiced. In much of the United States, the removal of residues would increase already intolerable levels of erosion and reduce long-term soil productivity. This would be an unacceptable result of residue collection. This analysis is therefore limited to the collection of those residues that can be removed without causing soil loss to exceed tolerance levels.

While the removal of residues causes the direct loss to the soil of the residues' nutrient and organic content, residue removal also causes an indirect loss. An increase in residue removal, even within the soil loss tolerance level, increases erosion. This eroded soil comes from the top, fertile, soil layer, which is higher in organic matter and nutrients than the soil underneath. The resulting indirect losses of nutrients and organic matter due to the erosion caused by residue removal may be 50 to 100 percent of direct losses from residue removal (Lockeretz, 1980).

In addition to the costs of erosion that accrue to a farmer, society incurs additional costs in the form of increased sedimentation in rivers and reservoirs, as well as increased water pollution from soil-associated pesticides, fertilizers, and organic matter.

To a certain extent, the problems of erosion caused by residue removal can be solved through the application of alternative conservation methods. These include: rotating crops; planting inter-row crops such as clover, alfalfa and winter vetch and then plowing these under as green manure; contour plowing; double cropping; strip cropping; terracing; and conservative tillage methods, such as chisel-plowing and no-till.

If the removal of all or some crop residues will not cause intolerable soil loss, or if that soil loss can be alleviated through conservation practices, then residues will be available as an energy source.

There is considerable attention aimed at the use of grain residue as a boiler fuel to heat the distillation of ethanol from grain. Although crop residues have the advantage of being low in sulfur compared with coal, coal is currently cheaper (OTA, 1980) as a boiler fuel than residues. This may seem counter-intuitive when one considers that these residues would otherwise decay in the fields, but the costs of utilizing them include the costs of purchasing harvesting equipment, harvesting and transporting residues, replacing lost fertilizer, and storing the residues for an average of six months between annual harvests.

As a feedstock, residues can be fermented to ethanol via enzymatic or acid hydrolysis, or converted to methanol. Although the use of agricultural residues as an alcohol feedstock is technologically feasible, current economics preclude the building of facilities for such production. Nevertheless, there is much current research in the field (Tyner, 1980).

In this appendix, estimates are developed of energy consumption resulting from the collection and of the overall availability of such residues.

E.1 Selection of Species

As stated above, this analysis is limited to developing energy estimates for the collection of residues from field crops, as opposed to the collection of residues available at a central facility.

Among those crop residues conventionally left in the field, corn and wheat residues are available in the greatest quantity. Soybeans, grain sorghum, rice, barley and oats also produce significant amounts of residues. Hay, all of which is harvested for feed, is not considered residue (Skidmore, 1979).

In assessing the types of residues suitable for methanol conversion, the ability of residues to be collected in the fall and stored until their use must be taken into account. Tyner (1980) notes that soybean residues decompose rapidly and therefore cannot be stored up to a year before they are used. Soybean residues are also difficult to collect. Therefore, soybean residues have been excluded from consideration in this analysis.

E.2 Selection of Sites

Those regions of the country that produce the greatest quantity of crops also produce the greatest quantity of crop residues: the Corn Belt and the Great Plains. Moreover, these regions produce crop residues beyond what is needed to control erosion, i.e., they produce residues available to support a methanol production facility. Within the Great Plains and Corn Belt regions, the only crops that produce available residues are corn and small grains.

Within each of these two regions, three Major Land Resource Areas (MLRA's) were selected for analysis. MLRA's are geographically-associated land resource units. States may contain 6 to 12 MLRA's (Gupta, 1979), although MLRA's cross state borders. In the Corn Belt region, the areas selected were: MLRA 102 located in southwestern Minnesota and eastern South Dakota; MLRA 115, located in southern Illinois and eastern Missouri; and MLRA 107, located mostly in western Iowa. In the Great Plains region, the areas selected were: MLRA 80, located in central Texas, central Oklahoma and southern Kansas; MLRA 73 located in north central Kansas and southern Nebraska; and MLRA 63, located in central South Dakota.

In selecting MLRA's for analysis, only those areas where residues can be collected without increasing soil erosion beyond tolerable levels have been considered. The three MLRA's analyzed in each region represent a range of the energy consumption per dry ton residue collected and delivered to a centrally-located conversion facility. In selecting these sites, no attempt was made to determine whether or not the collection of agricultural residues at these sites would be economic.

E.3 Energy Consumption Estimates

This section describes the methods used to derive energy consumption data per dry ton equivalent (DTE) of residues delivered to a centrally-located cellulose conversion facility in six MLRA's.

E.3.1 Literature Review

Numerous studies on the use of crop residues as an energy source were reviewed in a search for information relating to energy consumption in residue collection. Because of

the effect of residue availability on the energy used in transporting the residues, information was required on residue availability as well as on the energy requirements for residue collection activities.

A common, but incomplete, method of assessing total residue availability is to obtain published data on crop yields and to multiply those yields by the appropriate crop residue factor from the table below. The product is the total tonnage of residues by crop (Gupta, 1979).

Crop	Ratio of Straw Residue to Grain (by weight)
Corn	1:1
Sorghum	1:1
Spring wheat	1.3:1
Winter wheat	1.7:1
Durum wheat	1:1
Oats	2:1
Barley	1.5:1

This residue tonnage, summed across all crops, is the total residue produced. Much of this residue, however, cannot physically be collected, or would contribute to a significant erosion hazard if collected. Hence, total residue available for collection is significantly lower.

Tyner (1980) estimates that one ton of corn or sorghum residues per acre is uncollectable for residue yields of less than 5,300 lbs per acre. For yields higher than 5,300 lbs per acre, 37.5 percent of residues are uncollectable. For small grains, Tyner assumes that 500 lb of residues per acre cannot be collected.

In addition to this physical constraint, much of the collectible residue should be left on the soil to curtail water and/or wind erosion, reducing total residue availability further.

Only in the past few years have energy analysts considered the effect of residue removal on erosion, an effect long recognized by soil scientists. One reason for this delay may have been the difficulty in quantifying the impact of residues on erosion control. This impact will vary dramatically by site, thus calling into question

nationally-applied estimates such as those of Alich et al (1976) on typical residue availability.

The level of soil erosion is influenced by many factors. Water erosion depends on the level of rainfall, the soil type, the slope length, the slope gradient, the crop management technique, and an erosion control factor. These factors can be multiplied together using the universal soil loss equation (see Gupta, 1979) to produce estimates of soil loss due to water erosion. Wind erosion also depends on a variety of factors (soil erodibility, ridge roughness, climate, field length, and vegetative cover), but the relationship of these factors is sufficiently complex to require a computer program to calculate soil loss in each area (Posselius and Stout, 1980).

Thus, the determination of the amount of residues that can be removed for energy or other uses requires substantial site-specific data. For the present analysis, use has been made of data developed in a series of papers by Science and Education Administration (SEA) scientists (Larson, 1979; Gupta et al., 1979; Lindstrom et al., 1979; and Skidmore, et al., 1979). These papers provide estimates of the amount of residues that can be safely removed. The estimates were developed on the MLRA level; estimates of energy consumption per ton of residues developed in the present analysis have therefore been performed at the MLRA level.

The estimates of energy consumed in collection and transport of crop residues are based on equations developed by Clarence Richey for a Purdue University study for the OTA (Tyner, 1980). These equations estimate energy consumed in the collection of a specific type of residue from estimates of harvestable residue (in tons per acre) and the average distance to the conversion facility (in miles). These equations were selected because they take into account the effect of variations in residue availability on diesel fuel consumption.

E.3.2 Assumptions

In utilizing the data discussed above on residue availability, several assumptions have been made.

First, all residues available for harvest are assumed collected. However, because of the various hazards to the soil and other costs associated with residue collection, many farmers may fail to have crop residues collected on their lands. In some other areas, the tons per acre that can be removed safely is relatively low. As a result, the removal of such residues will be significantly less economic (in terms of energy as well as labor) than the removal of residues in areas where erosion is less of a problem. The assumption, then, that all residues available will be collected, is an optimistic one.

Second, all residues collected are assumed transported to a centrally-located methanol-producing facility. In reality, some of the residues would probably be kept on the farm for use as animal bedding or feed, but this is difficult to quantify.

Third, cropland is assumed to be uniformly distributed within an MLRA. This permits estimation of an average transport distance to a conversion facility for crop residues produced in the MLRA.

Fourth, a certain amount of solar drying of residues on the field is assumed. Such drying reduces bacterial losses as well as the weight of residues that must be transported to the conversion facility. Estimates of the moisture content of residues transported were obtained from Tyner (1979). These are: 12 percent moisture for small grains, and 15.5 percent moisture for corn residues after solar drying. At these moisture levels, the tons of residue needed for cellulose required for the conversion process is somewhat lower than if cellulose with 50 percent moisture is used. Accordingly, a 300,000 gallon/day methanol plant is estimated to require only about 1750 DTE of agricultural residues per day (as opposed to 2000 DTE per day when wood, with 50 percent moisture, is used).

E.3.3 Energy Input Estimates

There are several steps involved in the collection of agricultural residues. The residues are first cut close to the ground (a step which may occur routinely during harvest) and raked into windrows. The windrows are then gathered and packed into bales which are then moved to a roadside storage area. Finally, the bales are transported by truck to the processing facility.

Equations for energy consumption in each of these operations, in terms of diesel fuel consumed per acre, are presented in the previously mentioned Purdue study (Tyner, 1980). Converting the Purdue equations for corn and small grains to produce estimates of diesel fuel consumed per dry ton of residues yields:

	Diesel Fuel Consumption in Gallons/Dry Ton	
Operations	Corn residues (750 lb dry wt bale)	Small grain residues (665 lb dry wt bale)
Cut and windrow	1.18/R	0.61/R
Bale	0.262 + 1.11/R	0.295 + 0.77/R
Move to Roadside	0.51	0.574
Transport to Plant	0.067 + 0.059d	0.075 + 0.067d

where R is collectible residues, in dry tons per acre, and d is the average distance to the plant, in miles.

For the Great Plains MLRA's, collectible residues per acre, by crop, were obtained from estimates developed by Skidmore, Kumal and Larson (1979). These estimates were based on 1973-1975 data and reflect the maximum amount which can be collected without increasing soil loss due to wind erosion beyond tolerable levels.

For the Corn Belt MLRA's, collectible residues were estimated in a two-step process. First total residues produced per acre in the Corn Belt were derived from 1977-1979 estimates[1] of total residues produced by region and crop developed by Lockeretz (1980) and shown in Exhibit E-1. Then estimates of residues required to keep soil erosion below tolerance levels were subtracted.

The latter estimates were obtained from those developed by Lindstrom et al (1979) using 1972-1976 data. In the Corn Belt, water erosion is a more serious problem than wind erosion and residue requirements depend upon tillage practices. Lindstrom et al develop estimates for five different tillage practices. The estimates used in the present analysis assume the use of tillage methods (e.g., no-till) which permit the

[1] *Estimates of residue production are less sensitive to the years for which data is used than are estimates of crop yields, since adverse weather and pestilence generally reduce crop yields to a much greater extent than residue yields.*

EXHIBIT E-1: PRODUCTION OF MAJOR CROP RESIDUES[1], BY CROP AND REGION
(Million dry metric tons per year)

	Corn	Wheat	Soybeans	Sorghum	Oats	Barley	Total	
Corn Belt	98.5	9.9	43.5	1.8	3.8	0.1	157.5	(40%)
Northern Plains	27.4	31.0	4.1	10.0	5.8	4.1	82.4	(21%)
Lake States	28.4	5.3	7.4	—	5.8	1.7	48.6	(12%)
Southern Plains	3.9	13.1	1.2	6.4	0.8	0.2	25.6	(6%)
Mountain States	2.6	12.2	—	0.7	0.2	4.4	20.1	(5%)
Appalachia	8.6	1.7	6.3	0.1	0.2	0.3	17.2	(4%)
Pacific	1.8	9.8	—	0.3	0.4	2.6	14.9	(4%)
Delta	0.4	1.0	11.7	0.3	0.2	—	13.6	(3%)
Northeast	6.0	0.7	1.2	—	1.2	0.3	9.4	(2%)
Southeast	3.5	0.5	5.1	—	0.2	—	9.3	(2%)
U.S. (48 states)	181.1	85.2	80.5	19.6	18.6	13.6	398.6	(100%)
% of U.S.	(45%)	(22%)	(20%)	(5%)	(5%)	(3%)	(100%)	

[1] 1977-79 average, computed from state crop production data in Crop Production, 1979 Annual Summary. Residues computed from crop production using the following values for ratio of dry residue weight to harvested crop: corn, 1.0; spring wheat, 1.3; winter wheat, 1.7; durum wheat, 1.0; soybeans, 1.5; sorghum, 1.1; oats, 2.0; barley, 1.5 (Lindstrom et al., 1979). Data are for gross production only, with no allowances for losses in harvesting, competing uses, or soil conservation constraints on residue removal. Regions are those used by USDA for many statistical series (see Agricultural Statistics, 1978, p. 477 for a list of states in each).

Source: Lockeretz, 1980.

maximum removal of residues. Such methods are not always used and, because of potential problems with weeds, insects or drainage, they may not always be feasible (Lockeretz, 1980). Hence, the estimates used for available residues in Corn belt MLRA's may be overly optimistic and may result in underestimating energy requirements for residue collection in these areas.

For each of the six MLRA's, the total residue available was determined by multiplying the harvested crop acreage by the residue available per acre. This total was summed across all crops and divided by the land area of the MLRA[1] to obtain dry tons of available residues produced per square mile.

In the Corn Belt and Great Plains regions, crop residues can be harvested only once a year. Therefore, residues must be harvested from an area large enough to supply a conversion facility for an entire year.

As previously observed, a 300,000 gallon/day methanol plant requires about 1750 dry tons per day of agricultural residues. Allowing for bacterial, transport and storage losses of 15 percent (Tyner, 1980), the annual requirement for residues is about 750,000 dry tons per year. This figure was then divided by available residue production per square mile to obtain the (minimum) area necessary to provide residues for one 300,000 gallon/day methanol plant. Assuming a circular area and a centrally located plant yields an average transport distance of two-thirds the radius of the area.

As the equations presented earlier in this section show, energy consumption per ton of residues increases with decreased residue availability per acre and with increased average transport distance.

In addition to the direct use of energy in the harvesting of crop residues, significant indirect energy consuming elements must be considered as well. As stated in the introduction, the removal of residues will increase pollutants (difficult to quantify in energy terms) and reduce soil tilth (making the soil harder to plow).

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[1] *W. Larson and E. Skidmore, personal communications.*

One indirect energy cost which is significant and possibly quantifiable (though region and soil-type dependent) is lost grain production caused by a new harvest schedule. If winter rain or snow comes early, while a farmer is still harvesting crop residues, there may not be enough time for the farmer to prepare the ground for spring planting. This preparation must then take place in the spring, delaying planting and reducing yields (e.g., if plowing and fertilizing must be done in the spring instead of the fall, corn yields, especially susceptible to a shorter growing season, will suffer). According to a Purdue crop production model, using actual weather and field conditions data for 600 acres in Indiana for 1968-1974, the harvesting of residues would have resulted in an average reduction in corn production of 1.6 bu/acre. This would have been between one and two percent of total crop production.

For the Indiana study area, the Purdue study shows an average residue yield of 1.1 tons per acre. At an average loss of 1.6 bushels of corn per acre, each ton of residue harvested would have reduced corn production by approximately 1.5 bushels. The energy consumed in the production of the lost corn must be added to the energy cost of residue collection. Energy consumption for a small change in corn production was estimated on the basis of results from the Iowa State University linear-programming model of agricultural production. (See Section 2 of Appendix A for a description of this model.) Energy consumption per marginal bushel of corn was estimated by comparing the results of the base-case solution of this model (described in Exhibits A-19 through A-21 of Appendix A) to those of a second solution in which it was assumed that corn production would be increased by thirty million bushels[1] but no other changes in production would occur.

A much more significant indirect energy input to the collection of residues is the loss of the nutrient value of the residues. The organic content of the residues would be lost to the soil but would probably not be replaced. However, the common fertilizer elements (nitrogen, potassium and phosphorus) contained in the removed residues would have to be replaced with additional fertilizer, which has a very significant energy cost. Exhibit E-2 shows the nutrient content of the small grains and corn residues, as well as the total energy consumption of the manufacture of an equivalent amount of fertilizer.

[1] *A relatively large increase in corn production (thirty million bushels) was used to avoid the effect of local fluctuations in the energy response of the model to small changes in production. (These fluctuations in estimated energy consumption occur because the model's objective function is the minimization of cost, and not energy.)*

EXHIBIT E-2: IMBEDDED FERTILIZER IN CORN AND WHEAT RESIDUES PER DRY TON OF RESIDUES

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Liquid Fuels	Btu's Total Energy
	Energy in Fertilizer, (1); Nutrient content of residues, (2)							
• FERTILIZER IN CORN RESIDUES	1.1% N			0.012	574.7	0.0009		
	.1% P	0.00015	0.00066	0.020	27.0	0.00017		
	1.6% K			0.0002	37.1	0.0012		
	Total	0.00015	0.00066	0.0322	638.8	0.00227	4,900	707,600
• FERTILIZER IN WHEAT STRAW (similar for barley, oats) (2)	.5% N			0.0055	261.2	0.00042		
	.1% P	0.00015	0.00066	0.020	27.0	0.00017		
	.6% K			0.00008	13.9	0.00046		
	Total	0.00015	0.00066	0.02558	302.1	0.00105	4,000	335,700

Sources
(1) Derived from: Tyson, Belzer and Associates, 1980.
(2) S. Kresovich, Personal Communication.

In the first year following their return to the soil, perhaps only 2 to 3 percent of residue nutrients would be available. Over time, however, much of the nutrients would be available as a natural fertilizer. However, erosion and/or minerals in the soil would reduce the value of residues as fertilizer. The phosphorus in residues, in particular, may form compounds with other elements in the soil and, therefore, has little value as fertilizer.

The estimates of energy consumption for collecting residues in each of the six selected MLRA's are presented in Exhibits E-3 through E-8. For each MLRA, the estimates for corn and for small grains are developed separately and then combined on the basis of the relative production of the two categories of residue. The estimates for the six MLRA's are summarized in Exhibit E-9.

The largest input in almost all of the MLRA's is the fertilizer value of the residues, an indirect energy input. The second largest input is the energy cost of transporting the residues, reflecting the extreme sensitivity that residue collection costs have with respect to transportation distances. Notably, the total energy consumption estimates in five of the six MLRA's are quite similar (between 1.4 MM and 1.9 MM Btu), while they are about double this value in MLRA 63, where expected residue yields per acre are low and estimated transport distances high. This emphasizes the relative sensitivity of these results to transport distances and expected residue yields.

E.3.4 Possibilities for Reduced Energy Consumption

Probably the most significant reduction in energy consumption could be achieved by reducing the capacity of the methanol production facility. The smaller the facility, the smaller the average distance that residues must be transported. In view of the size of the transportation energy input, this could produce a significant energy saving.

Another interesting possibility would be the use of combines that harvest and bale residues at the same time as grain. Such combines would: eliminate the need to travel over each acre twice to collect residues (a considerable savings in labor as well as energy); and increase the amount of residues that can be physically collected (due to improved harvesting equipment). On the other hand, the use of such combines would tend to: increase the length of the grain harvest, which may endanger crop collection;

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102
(Northeastern Nebraska, Southeastern South Dakota and Southwestern Minnesota)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 1.08 tons/acre (1) Average transport distance (d): 20.8 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		1.09					153,000	153,000
	—Bale		1.29					180,600	180,600
	—Move to Roadside		0.51					71,400	71,400
	—Transport to Plant		1.29					181,200	181,200
— Fertilizer (4)		0.00015	0.00066	0.032		639	0.00227	4,900	707,600
— Reduced Corn Production (5)		—	0.22	—	0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	4.41	0.032	0.11	699	0.00320	632,300	1,417,200
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	0.78	0.006	0.02	123	0.00056	111,600	250,100
TOTAL	CORN RESIDUES — MLRA 102	0.00018	5.19	0.038	0.13	822	0.00376	743,900	1,667,300

Sources

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Corn production reduced on average by about 1.5 bushels per ton of residues collected (see text); energy consumption shown is estimated energy required to produce a compensating increase in corn production as estimated by ISU Model (see text).

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.39 tons/acre (1) Average transport distance (d): 20.8 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		0.44					61,600	61,600
	— Bale		0.85					118,900	118,900
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		1.47					205,600	205,600
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	3.55	0.026	0.11	362	0.00198	511,600	925,600
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	0.63	0.005	0.02	64	0.00035	90,300	163,300
TOTAL	SMALL GRAINS RESIDUES — MLRA 102	0.00018	4.18	0.031	0.13	426	0.00233	601,900	1,088,900

Sources:

(1) - (4) See first page of this exhibit.

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102

(Continued)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.57 tons corn and 0.43 tons small grains:								
	Corn residues	0.00010	2.95	0.022	0.07	469	0.00214	424,000	950,400
	Small grain residues	0.00008	1.80	0.013	0.06	183	0.00100	258,800	468,200
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 102	0.00018	4.75	0.035	0.13	652	0.00314	682,800	1,418,600

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115
(East Central Missouri and West Central Illinois)

Energy Consuming Element	Assumptions	Petroleum Products							
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 0.95 tons/acre (1) Average transport distance (d): 32.2 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		1.24					173,900	173,900
	— Bale		1.43					200,400	200,400
	— Move to Roadside		0.51					71,400	71,400
	— Transport to Plant		1.97					275,400	275,400
— Fertilizer (4)		0.00015	0.00066	0.032		639	0.00227	4,900	707,600
— Reduced Corn Production (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	5.37	0.032	0.11	699	0.00320	767,200	1,552,100
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00002	0.95	0.006	0.02	123	0.00056	135,400	273,900
TOTAL	CORN RESIDUES — MLRA 115	0.00018	6.32	0.038	0.13	822	0.00376	902,600	1,826,000

Sources

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Corn production reduced on average by about 1.5 bushels per ton of residues collected (see text); energy consumption shown is estimated energy required to produce a compensating increase in corn production as estimated by ISU Model (see text).

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115
(Continued)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.24 tons/acre (1) Average transport distance (d): 32.2 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		0.49					68,900	68,900
	— Bale		0.92					128,200	128,200
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		2.23					312,500	312,500
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)		―	0.22	―	0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	4.43	0.026	0.11	362	0.00198	635,100	1,049,100
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	0.78	0.005	0.02	64	0.00035	112,100	185,100
TOTAL	SMALL GRAIN RESIDUES — MLRA 115	0.00018	5.21	0.031	0.13	426	0.00233	747,200	1,234,200

Sources

(1) - (4) See first page of this exhibit
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.69 tons corn and 0.31 tons small grains:								
	Corn residues	0.00012	4.36	0.026	0.09	567	0.00259	622,800	1,259,900
	Small grain residues	0.00006	1.62	0.010	0.04	132	0.00072	231,600	382,600
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 115	0.00018	5.98	0.036	0.13	699	0.00331	854,400	1,642,500

EXHIBIT E-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107
(Northwestern Missouri and Southwestern Iowa)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 1.02 tons/acre (1) Average transport distance (d): 31.5 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		1.16					162,000	162,000
	— Bale		1.38					193,200	193,200
	— Move to Roadside		0.51					71,400	71,400
	— Transport to Plant		1.93					269,600	269,600
— Fertilizer (4)		0.00015	0.00066	0.032		639	0.00227	4,900	707,600
— Reduced Corn Production (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	5.20	0.032	0.11	699	0.00320	742,300	1,527,200
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	0.92	0.006	0.02	123	0.00056	131,000	269,500
TOTAL	CORN RESIDUES — MLRA 107	0.00018	6.12	0.038	0.13	822	0.00376	873,300	1,796,700

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Corn production reduced on average by about 1.5 bushels per ton of residues collected (see text); energy consumption shown is estimated energy required to produce a compensating increase in corn production as estimated by ISU Model (see text).

EXHIBIT E-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107
(Continued)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.02 tons/acre (1) Average transport distance (d): 31.5 mi (2)								
— Harvest and Transport (3)	—Cut and windrow —Bale —Move to Roadside —Transport to Plant		0.46 1.06 0.57 2.19					64,700 148,400 80,400 306,000	64,700 148,400 80,400 306,000
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	4.50	0.026	0.11	362	0.00198	644,600	1,058,600
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	0.79	0.005	0.02	64	0.00035	113,800	186,800
TOTAL	SMALL GRAIN RESIDUES — MLRA 107	0.00018	5.29	0.031	0.13	426	0.00233	758,400	1,245,400

Sources

(1) - (4) See first page of this exhibit

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.84 tons corn and 0.16 tons small grains:								
	Corn residues	0.00015	5.14	0.032	0.11	690	0.00316	733,600	1,509,200
	Small grain residues	0.00003	0.85	0.005	0.02	68	0.00037	121,300	199,300
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 107	0.00018	5.99	0.037	0.13	758	0.000353	854,900	1,708,500

EXHIBIT E-6: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 80
(Oklahoma and Texas prairie)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 0.66 tons/acre (1) Average transport distance (d): 36.1 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		0.92					129,400	129,400
	— Bale		1.46					204,600	204,600
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		2.49					349,100	349,100
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)			0.22	0.002	0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	5.66	0.026	0.11	362	0.00198	808,600	1,222,600
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	1.00	0.005	0.02	64	0.00035	142,700	215,800
TOTAL	SMALL GRAIN RESIDUES — MLRA 80	0.00018	6.66	0.031	0.13	426	0.00233	951,300	1,438,400

Sources

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of preceding exhibit).

EXHIBIT E-6: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 80
(Continued)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 1.00 tons small grains	0.00018	6.66	0.031	0.13	426	0.00233	951,300	1,438,400
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 80	0.00018	6.66	0.031	0.13	426	0.00233	951,300	1,438,400

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73
(South Central Nebraska and North Central Kansas)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 0.89 tons/acre (1) Average transport distance (d): 41.8 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		1.33					185,600	185,600
	—Bale		1.51					211,300	211,300
	—Move to Roadside		0.51					71,400	71,400
	—Transport to Plant		2.53					354,600	354,600
— Fertilizer (4)		0.00015	0.00066	0.032		639	0.00227	4,900	707,600
— Reduced Corn Production (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	6.10	0.032	0.11	699	0.00320	869,000	1,653,900
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	1.08	0.006	0.02	123	0.00056	153,400	291,900
TOTAL	CORN RESIDUES — MLRA 73	0.00018	7.18	0.038	0.13	822	0.00376	1,022,400	1,945,800

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Corn production reduced on average by about 1.5 bushels per ton of residues collected (see text); energy consumption shown is estimated energy required to produce a compensating increase in corn production as estimated by ISU Model (see text).

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 0.35 tons/acre (1) Average transport distance (d): 41.8 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		1.74					244,000	244,000
	— Bale		2.50					349,300	349,300
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		2.88					402,600	402,600
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)			0.22		0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	7.91	0.026	0.11	362	0.00198	1,121,400	1,535,400
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	1.40	0.005	0.02	64	0.00035	197,900	271,000
TOTAL	SMALL GRAIN RESIDUES — MLRA 73	0.00018	9.31	0.031	0.13	426	0.00233	1,319,300	1,806,400

Sources

(1) - (4) See first page of this exhibit

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.295 tons corn and 0.705 tons small grains:								
	Corn residues	0.00005	2.19	0.011	0.04	242	0.00111	301,600	574,000
	Small grain residues	0.00013	6.56	0.022	0.09	300	0.00164	930,100	1,273,500
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 73	0.00018	8.75	0.033	0.13	542	0.00275	1,231,700	1,847,500

EXHIBIT E-8: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 63
(West Central South Dakota)

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAINS RESIDUES	Collectible residues (R): 0.18 tons/acre (1) Average transport distance (d): 144.9 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		3.39					474,400	474,400
	— Bale		4.57					640,200	640,200
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		9.78					1,369,700	1,369,700
— Fertilizer (4)		0.00015	0.00066	0.026		302	0.00105	3,900	335,700
— Reduced Corn Production (5)		____	0.22	____	0.11	60	0.00093	41,200	123,400
SUBTOTAL		0.00015	18.53	0.026	0.11	362	0.00198	2,609,800	3,023,800
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.00003	3.27	0.005	0.02	64	0.00035	460,600	533,600
TOTAL	SMALL GRAIN RESIDUES — MLRA 63	0.00018	21.80	0.031	0.13	426	0.00233	3,070,400	3,557,400

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of preceding exhibit).

EXHIBIT E-8: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 63
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 1.00 tons small grains	0.00018	21.80	0.031	0.13	426	0.00233	3,070,400	3,557,400
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 63	0.00018	21.80	0.031	0.13	426	0.00233	3,070,400	3,557,400

EXHIBIT E-9: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES: SUMMARY OF ALL MLRA'S ANALYZED

	Petroleum Products							
	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal[1] (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN BELT								
Major Land Resource Area 102	0.00018	4.75	0.035	0.13	652	0.00314	682,800	1,418,600
Major Land Resource Area 115	0.00018	5.98	0.036	0.13	699	0.00331	854,400	1,642,500
Major Land Resource Area 107	0.00018	5.99	0.037	0.13	758	0.00353	854,900	1,708,500
• GREAT PLAINS								
Major Land Resource Area 80	0.00018	6.66	0.031	0.13	426	0.00233	951,300	1,438,400
Major Land Resource Area 73	0.00018	8.75	0.033	0.13	542	0.00275	1,231,700	1,847,500
Major Land Resource Area 63	0.00018	21.80	0.031	0.13	426	0.00233	3,070,400	3,557,400

(1) Based on 11,250 Btu/lb bituminous coal.

require the baling of wet residues, which are more susceptible to bacterial degradation than dry residues; and require considerable investment in the form of new equipment.

E.4 Potential Availability of Residues

The Science Education Administration study from which the data on harvestable residues were obtained examined residue availability in six southern states and in eastern Oregon, in addition to the Corn Belt and the Great Plains. Tyner (1980) expanded on this work, developing estimates of residue availability for the rest of the country. That report's final estimate of total residues available for collection in the United States is shown in Exhibit E-10. Note that usable residues represent only one-fifth of total residues produced (previously shown in Exhibit E-1).

The amount of harvestable residue that would actually be collected would be smaller than the available residues estimated in Exhibit E-10. Farmers may be reluctant to invest the time and money necessary to collect the residues if only a small portion of the residues may be safely removed, or they may not wish to remove the residues at all, in view of the nutrients the residues provide to the soil and their erosion-reducing properties. Also, as stated earlier, not all residues collected are available for conversion to cellulose. Some are used on the farm or sold to livestock producers for animal feed or bedding. Collected residues may also be used as a heat source through direct combustion.

Significant quantities of collectible residues are available primarily from prime farm land: very flat land (less than two percent slope) with rich, deep soil. Most such land is already being farmed. Hence, potential additions to cropland are likely to come primarily from more marginal farm land and are not likely to be capable of supplying significant quantities of residues.

In areas of low usable residue density, transport costs will be high, and the building of a capital-intensive conversion facility would be unlikely. Soil, climate and productivity conditions combine to make five states the producers of 48 percent of the usable crop residues in the United States. Eleven other states produce 35 percent, and the

EXHIBIT E-10: TOTAL USABLE CROP RESIDUE IN THE UNITED STATES BY CROP

Crop	Amount (M tons)	Harvestable Acres (M acres)	Average Yield (tons/acre)
Corn	37,098	39,122	.95
Small grains	33,623	36,324	.93
Sorghum	1,452	4,100	.35
Rice	5,457	2,516	2.17
Sugar	590	331	1.78
Total	78,220	82,393	.95

Source: Tyner, 1980.

remaining 32 states in the lower 48 combined produce only 17 percent of the usable residues. Given this distribution of residue availability, residues for alcohol production are likely to come primarily from the top twelve states[1] (which produce 73 percent of the total available residues).

[1] *In order of usable residue production, these states are: Minnesota, Illinois, Iowa, Indiana, Ohio, Wisconsin, California, Washington, Kansas, Nebraska, Texas and Arkansas.*

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APPENDIX F

METHANOL FROM CELLULOSIC FEEDSTOCKS

In this appendix, estimates are developed of the energy inputs and outputs for the production of methanol from cellulosic materials. Production of methanol from cellulose involves drying the cellulosic feedstock to ten percent moisture and decomposing it at a high temperature to produce synthesis gas. This gas is primarily carbon monoxide (CO) and hydrogen (H_2). Steam is added to the gas; impurities are removed; and the gas is condensed under high pressure to form methanol. Distillation then removes any other impurities. The production process is described in somewhat more detail below.

F.1 Selection of Technology

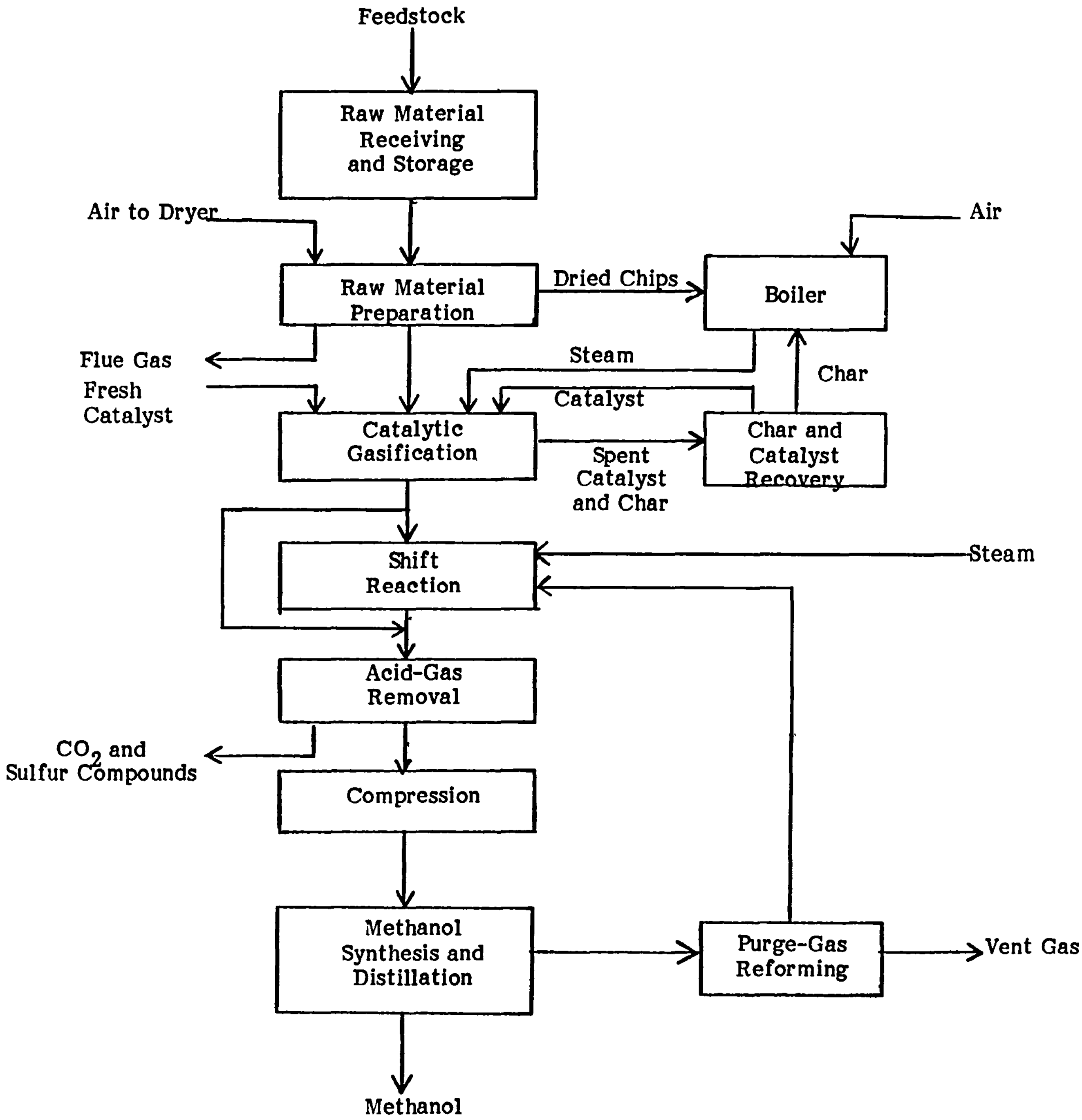
At the present time, none of the technologies for conversion of wood or other cellulosic materials to methanol are considered commercially proven. Nevertheless, the equipment used in much of the process described below is proven in other, similar, commercial applications. Of the various process steps, only the gasification of wood has not been demonstrated on a commercial scale.

The technology selected for this energy analysis comes from a recent study (Mudge et al, 1981) that combines the Battelle Pacific Northwest Laboratories catalytic wood gasification technology, the Benfield acid gas removal technology, and the ICI methanol synthesis technology. The overall process flow is presented in Exhibit F-1.

F.2 Process Description

The raw material for the methanol plant can be either green wood or agricultural residues. These are received by truck trailers (already chipped), weighed, and placed in storage via a chain feeder and tripper/stacker belt conveyor. The quantities of feedstock that must be kept in storage will vary by type of feedstock, size of plant, and seasonality of the raw material. However, storage capacity must be sufficient to ensure continuous plant operation.

EXHIBIT F-1: SIMPLIFIED FLOWCHART OF CELLULOSE-TO-METHANOL PROCESS



The chips are reclaimed from storage via chain reclaimers and delivered to the primary screening section using belt conveyors. The screening station contains equipment for rock and tramp iron removal and for rechipping oversize chips. From here, the chips are sent to the drying section complete with rotary drum dryers, burners, ash removal systems, cyclones, ducting, and other equipment necessary to reduce the moisture content of the green chips from 50 percent (by weight) to 10 percent. The dryers are fueled by the the by-product char from the gasifiers.

The dried chips are then conveyed to the gasifier feed bin. Approximately 14 percent of the dry wood entering the gasification section is burned to heat the gasifiers; the remaining chips are then screw fed continuously to the base of the gasifiers through a lock-hopper system. The gasifiers are of fludized-bed type and contain spherical balls of nickel catalyst on a silica-alumina structure. High-pressure steam is introduced into the gasifiers both for the gasification reactions and to fluidize the solids.

The gasifiers operate at 150 psia and 1380° F. At these conditions, most hydrocarbons are cracked to produce synthesis gas containing primarily hydrogen and carbon oxides with a small amount of methane. Char and catalyst particles are continuously removed from the gasifiers through a lock-hopper system. The catalyst, after recovery, is recycled to the gasifiers, while char is used as process fuel.

The hot raw synthesis gas from the gasifiers is then cooled to 350° F in a series of heat exchangers which recover heat by generating superheated steam at 600 psig. Entrained solids (catalyst and char particles) from the cooled gas are removed by cyclones and bag filters.

The synthesis gas is then sent to the shift section. Only part of the synthesis gas must be reacted with steam to achieve the desired ratio of carbon monoxide to hydrogen. The rest of the gas bypasses the shift reactor.

The gas from the shift reactors then flows to the acid-removal section where carbon dioxide and any traces of sulfur-containing compounds are removed by the Benfield process. The gas is then compressed to 1000 psig with a multistage centrifugal compressor. The purified, compressed synthesis gas is finally converted to methanol by the ICI low-pressure methanol process. The product gas containing methanol, water vapor, and unreacted gases is condensed and purified by distillation. Heat recovered

during condensation is used to purify the methanol and to preheat incoming feed gas. Light ends containing dimethyl ether and sidestream containing higher alcohols are removed separately and used as process fuel.

During methanol synthesis, a small amount of purge steam is periodically removed from the methanol reactors and sent to a reformer. This stream, containing hydrocarbons (essentially methane) that build up in the system, is converted to hydrogen and carbon oxides in the reformer. Following heat recovery, the reformed gas is sent to the shift reactor.

Steam for the process is generated in heat exchangers and in the main boiler. The main boiler is fired mainly by gasifier char, but it also uses a small amount of wood, the light ends, and fusel oil from the methanol distillation.

F.3 Process Chemistry

The chemistry of gasifying wood and other cellulosic materials is complex. The overall reactions have been simplified for the purpose of illustration.

In the gasifier, cellulose, hemicellulose and lignin in the wood are reacted with steam to form synthesis gas. The major reactions are

$$(CH_2O)_x + H_2O = xCO + xH_2 + H_2O$$

$$(CH_2O)_x + xH_2O = xCO_2 + 2xH_2$$

$$(CH_2O)_x = xC + xH_2O$$

$$C + H_2O = CO + H_2$$

$$2(CH_2O)_x = xCO_2 + xCH_4$$

The water shift reaction is used to adjust the ratio of carbon monoxide to hydrogen for methanol synthesis.

$$CO + H_2O = CO_2 + H_2$$

Acid gas removal with a Benfield system involves absorbtion in hot potassium carbonate to form bicarbonate (or bisulfide).

$$K_2CO_3 + CO_2 + H_2O = 2KHCO_3$$

The absorbent is regenerated by the reverse reaction.

The methanol synthesis is accomplished by the catalytic reaction of carbon monoxide with hydrogen.

$$CO + 2H_2 = CH_3OH$$

Purge gas from the methanol synthesis loop containing methane is reformed with steam to produce hydrogen which is then recycled to the shift reactor.

$$CH_4 + H_2O = CO + 3H_2$$

$$CH_4 + 2H_2O = CO_2 + 4H_2$$

F.4 Energy Consumption Estimates

The inputs to the methanol process are given below. The data are presented per unit of methanol:

Dry Wood	6.63 ton/1,000 gal or
Dry Agricultural Residues	5.8 ton/1,000 gal
Electricity	1,767 kwhr/1,000 gal
Diesel Fuel	1.09 gal/1,000 gal

The diesel fuel is consumed by bulldozers in the wood storage area; the electricity and wood are consumed in the process.

The consumption of energy by type within the process is shown in Exhibit F-2 for wood. The reader is cautioned that the energy consumed by each process section may vary considerably from one design to another due to the placement of heat exchangers and other energy conserving equipment.

Exhibit F-3 summarizes energy inputs to methanol from cellulose. Exhibit F-4 presents the energy output. Cellulose and energy requirements for producing a given amount of methanol varies a function of the moisture content of the feedstock.

F.5 Sensitivity Analyses

Plant Size. The process plant energy requirements per ton of raw material are not a function of plant scale. The energy needed to transport raw material to the plant, however, does depend on plant size. An economic plant would process about 2,000 dry tons of wood per day to make about 1,000 tons of methanol (300,000 gal) per day. A plant processing about 1,000 dry tons would be close to the lower limit of economic size. The upper limit is dependent on transportation costs; the maximum plant size is probably about 5,000 DTE of wood per day. Between those two bounds the process energy balance is independent of plant size.

Feedstock. Virtually any cellulosic feedstock can be gasified and the resulting synthesis gas converted to methanol. The energy balance will be sensitive to the moisture in the feed. Variations in ash content will have a negligible impact on the energy balance. The raw wood composition assumed was 49.5 percent moisture. This is typical of forest residues and wood from a silvicultural farm. Agricultural residues may have a lower moisture content, depending on the amount of solar drying in the field. For this analysis, corn residues were assumed to be 15.5 percent moisture; small grains residues were assumed to be 12 percent moisture (Tyner, 1980). These lower levels of moisture resulted in estimated energy savings of .23 and .24 Btu of wood per Btu of methanol, respectively. The sensitivity to moisture content is nonlinear.

The moisture content of wood is more or less independent of weather, although it could increase somewhat during storage in a rainy season or decrease during a dry season. The moisture content of agricultural residues will be more variable and particularly more sensitive to weather conditions immediately prior to collection.

EXHIBIT F-2: METHANOL FROM WOOD ENERGY BALANCE
PNL/ICI PROCESS

Process Section	Dry Wood tons per 10^6 Btu Methanol	Electricity[2]	Char (Dry) Btu per Btu Methanol	By-Product Fuel Btu per Btu Methanol	hp Steam[1] Consumed Btu per Btu Methanol	hp Steam[1] Produced Btu per Btu Methanol	lp Steam[1] Consumed Btu per Btu Methanol	lp Steam[1] Produced Btu per Btu Methanol
Feed Preparation & Drying		-	-0.251					
Gasification	-1.019	-	+0.346		0.145	0.095		0.029
Shift		-						0.062
Acid Gas Removal		-					0.092	
Compression		--						
Methanol Synthesis		-		+0.134				
Reforming		-		-0.082	0.097			
Steam Generation	-0.011	-	-0.095	-0.052		0.147		
Miscellaneous		-						
TOTAL	-1.03	-0.286	0	0	0		0	

[1] hp steam is 600 psig, 750 F; lp steam is 150 psig saturated. Energy of steam taken as enthalpy above water at 0 C (32 F).

[2] Electricity consumption by process section not available. Some electricity consumed in each section, greatest amount consumed in compression.

N.B. Process requirements shown on this table apply only to wood. Energy inputs are somewhat lower for the process fed by agricultural residues.

EXHIBIT F-3: ENERGY INPUT ESTIMATES FOR THE METHANOL CONVERSION FACILITY PER 1000 GALLONS METHANOL PRODUCED

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal[1] (tons)	Btu's Petroleum Products	Btu's Total Energy
	<u>Feedstock Requirements</u>							
	6.63 DTE Wood 5.8 DTE Agricultural Residues							
• STORAGE	- Bulldozers move and reclaim feedstock		1.09				152,600	152,600
• PROCESS	- Most energy from feedstock							
	- Electricity, 1,767 kwhr[2]					0.82		18,393,900
	TOTAL PROCESS ENERGY INPUTS		1.09			0.82	152,600	18,546,500

(1) Based on use of 11,250 Btu/lb bituminous coal.
(2) Electricity requirement is for wood feedstock (see Exhibit F-2). Requirement is somewhat lower when agricultural residues are used.

EXHIBIT F-4: ENERGY OUTPUT ESTIMATES FOR THE METHANOL CONVERSION FACILITY PER 1000 GALLONS OF METHANOL PRODUCED

			Petroleum Products						
	Energy Output Estimate	Methanol (gal)	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Liquid Fuels	Btu's Total Energy
•	METHANOL	1,000						64,350,000	64,350,000
TOTAL	METHANOL	1,000						64,350,000	64,350,000

BIBLIOGRAPHY FOR APPENDICES C THROUGH F

The following partially annotated bibliography contains listings for the sources used in Appendices C-F.

Alich, J.A., Jr. and Inman, R.E., Effective Utilization of Solar Energy to Produce Clean Fuel, Stanford Research Institute, Menlo Park, CA (1974).

Presents initial work on energy inputs and outputs for a proposed silvicultural biomass farm design.

Alich, J.A., Jr.; Inman, R.E.; Ernest, K.; et al., Evaluation of the Use of Agricultural Residues as Energy Feedstock, Vol. I, Stanford Research Institute. Springfield, VA: NTIS, #PB-260763 (July 1976).

Since agricultural residues (crop and forest wastes and animal manures) constitute a potential supplemental source of energy, the authors examine the availability of such residues and evaluate their potential use as an energy feedstock. The research objectives are to: (1) develop a nationwide county-by-county inventory of residues generated, their quantity and condition, their current uses or disposal practices, their net availability, location, distribution and seasonality, and a computer file as an aid in summarization and analysis; and (2) assess the practicality and costs of collecting and using residues on the basis of geographic concentration patterns and the economics of collection, transportation, and usage. The report is presented in two volumes: the method of approach used in inventory development, the collection, harvesting, and conversion economics, and the overall concept assessment are presented in Volume I. (Author's abstract).

The data used are averaged over 1971-73. They present residue factors and percent dry weight for many crops.

Allmaras, R.R.; Gupta, S.C.; Pikul, J.F., Jr.; and Johnson, C.E., "Tillage and Plant Residue Management for Water Erosion Control on Agricultural Land in Eastern Oregon," Journal of Soil and Water Conservation 34:2 (1979).

We estimated soil erosion by water in the major land resource areas (B7, B8, B9) of eastern Oregon. Combinations of tillage and crop residue handling, terracing, and contouring were evaluated as control alternatives. Wheat-fallow, especially, and wheat-pea sequences predominated. Soil erosion exceeded tolerance limits in the wheat-fallow sequence on slopes over 20 percent even with all three management inputs. All three management inputs were needed on slopes between 12 and 20 percent. Tillage and residue management, along with contouring, sufficed on slopes less than 12 percent. The three major land resource areas in eastern Oregon (1.94 million hectares) produce 1.3 million metric tons of small grain residues annually, 60 percent of which can be harvested from 88 percent of the 344,200 hectares harvested. (Author's abstract).

American Pulpwood Association, "Fuel Survey." Washington, D.C.: American Pulpwood Association (1975).

This source reports average fuel consumption rates for various equipment used in 11 basic pulpwood logging systems — averaged over pulpwood operations in the South, Northeast, and Lake States.

types and amounts of energy utilized, their sources, points of consumption and patterns of flow, State energy consumption and production, and geographic extent and nature upon which energy resources are drawn. (Data base abstract).

Cullen, D.E. and Barr, W.J., Harvesting of Close-Spaced Short-Rotation Woody Biomass. Princceton, NJ: Mathtech, Inc. (1980).

Davis, C.H., and Blouin, G.M., Energy Consumption in the U.S. Chemical Fertilizer System from the Ground to the Ground. Muscle Shoals, AL: Tennessee Valley Authority Division of Chemical Development (1976).

This paper presents data on all energy used in fertilizer production from the mining of fertilizer feedstocks to the application of the final product.

The paper includes maps that locate plants producing the various fertilizers.

Davis, C.H. and Blouin, G.M., Fertilizers, Energy, and Opportunities for Conservation. Muscle Shoals, AL: Tennessee Valley Authority Division of Chemical Development (1980).

This paper looks at the high cost of natural gas and recent industry conservation developments.

The authors believe that ammonia can be made more cheaply from coal than from natural gas at its free market price.

Davis, C.H., and Blouin, G.M., "How Much Energy Does Fertilizer Consume?," Farm Chemicals 140:6, pp. 18-20, 22 (1977).

This article describes the synthetic procedures and energy used to produce the most common forms of fertilizer.

Davy McKee Corporation, Report and Analysis of Plant Conversion Potential to Fuel Alcohol Production. Washington D.C.: National Alcohol Fuels Commission (1980).

This report presents data and other information on excess and idle alcohol production capacity. The report lists those factories available for alcohol production, for the following types:

- Distilleries
- Breweries
- Wet Corn Milling
- Sugar Factories
- Cheese Whey
- Potato Byproducts
- Citrus Waste

For each of these factory types, the report describes the process used and the energy type and input necessary to make alcohol.

Fege, A., "Energy From Biomass," Solar Energy Handbook. Edited by J.F. Kreider and F. Kreith, Chapter 25. New York, NY: McGraw-Hill Publishing Co. (1981).

This chapter discusses basis for converting solar energy into the classical energy content of plants — the biomass resource base; the processes for converting biomass to useful fuels, and the concept of silvicultural energy farming as a promising future system for increasing the amount of energy supplied by biomass. (Author's summary).

Fege, A.S.; Inman, R.E.; and Salo, D.J., "Energy Farms for the Future," Journal of Forestry. Washington, D.C.: Society of American Foresters, pp. 358-361 (1979).

Silviculture energy farms may provide wood for energy at competitive prices in the future. In a study undertaken for the Department of Energy, costs were projected at $20 to $34 per dry ton for hardwoods grown under 2 to 10 year rotations. The major costs were estimated to be harvest and transportation to conversion facility, and such intensive cultural practices such as fertilization and irrigation. Up to 4.5 quads (10^{15} Btu per quad) of energy feedstocks could be produced in the United States annually, at an average annual yield of 8 dry tons per acre. The authors assume 30 million acres of land would be available for energy farm use out of the 300 million acres possible. (Author's abstract).

Flaim, S.J., Neenan, B., Dauve, J., and Map, H.P., Jr., Costs for Alternative Grain Residue Collection Systems. Golden, CO: Solar Energy Research Institute (June 1981).

Gasohol Study Group, Report of the Energy Research Advisory Board on Gasohol. Washington, D.C.: DOE (1980).

This study examines the net energy and economic benefits of gasohol production.

Gasslander, J.E.; Mattsson, J.E.; and Sundberg, U., A Pilot Study on the Energy Requirements in Forest Logging. Garpenberg, Sweden: Swedish University of Agricultural Sciences (1979).

Georgia Forestry Commission, Forest Management Department, Fuel Consumption -- Whole Tree Chipping Operation. Macon, Georgia: Georgia Forestry Commission (1980).

This source presents fuel consumption rates for a whole tree chipping operation, for light, medium, and heavy site preparation, and for tree planting.

Gupta, S.C.; Onstad, C.A.; and Larson, W.E., "Predicting the Effects of Tillage and Crop Residue Management on Soil Erosion," Journal of Soil and Water Conservation, 34:2 (1979).

Using the universal soil loss equation, we delineated those areas from which crop residues could be removed from the soil surface for other uses without erosion exceeding the soil loss tolerance limit. We also calculated the amount of crop residues produced, and determined the amounts available for removal. Here we present the sources of data and computation procedures used in this study and illustrate the kind of information available from the computer analysis. (Author's abstract).

Hall, E.H.; Allen, C.M.; Ball, D.A.; Burch, J.E.; Conkle, H.N.; Lawhon, W.T.; Thomas, T.J.; and Smithson, G.R., Comparison of Fossil and Wood Fuels. Prepared for the U.S. EPA. Columbus, Ohio: Battelle-Columbus Laboratories (1975).

Hall, E.H.; Burch, J.E.; Eischen, M.E.; and Hale, R.W., Environmental and Technological Analysis of the Use of Surplus Wood as an Industrial Fuel. Prepared for the U.S. EPA. Columbus, Ohio: Battelle-Columbus Laboratories (1980).

Hannon, B. and Perez Blanco, H., Ethanol and Methanol as Industrial Feedstocks, University of Illinois at Urbana-Champaign (1979).

This paper contains data on energy consumption on two methods each of manufacturing ethanol and methanol. The paper also lists many valuable references.

Hansson, L.R., "Bio-Energy in Sweden: Energy Plantation Overview," Bio-Energy Conference Proceedings. Washington, D.C.: Bio-Energy Council (1980).

Description of Sweden's plans for short-rotation energy plantations.

Haynes, V.O., Energy Use in Petroleum Refineries. Springfield, VA: NTIS, #ORNL/TM-5433 (1976).

This volume presents detailed information on petroleum refining processes and energy consumption required by fuel type.

Hittman Associates, Inc., Fuel Energy Consumption in the Coal Industries. Springfield, VA: NTIS, #PB-237 151/GSL (1974).

Information on the basic structure and characteristics of the coal mining industry is presented. Particular emphasis is placed on fuel use by major type and production process and exploring possibilities for fuel substitutability and conservation alternatives. (Data base abstract).

This report analyzes Census of Mineral Industries data from 1967.

Hoeft, R.G. and J.C. Siemens, Energy Consumption and Return from Adding Nitrogen to Corn, Illinois Agricultural Experiment Station (1975).

Holt, R.F., "Crop Residue, Soil Erosion, and Plant Nutrient Relationships," Journal of Soil and Water Conservation 34:2 (1979).

Crop residues contain plant nutrients that must be replaced if the residues are removed from the field. Removal of crop residues will increase wind and water erosion, and the eroded sediment will carry plant nutrients with it. The combined nutrient removal in residues and erosion under existing cropping practices would be greater in the Corn Belt than in the Southeast, central Oregon, or the Great Plains. (Author's abstract).

Howlett, K. and Gamache, A., Silvicultural Biomass Farms -- Forest and Mill Residues as Potential Sources of Biomass. Prepared for U.S. Department of Energy. Springfield, VA: NTIS (1977).

Hypes, T.L. and Stuart, W.B., "Preliminary Analysis of Harvesting Costs by Diameter Class," Industrial Forestry Operations Program, School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA (1981).

This source analyzes harvesting costs relative to tree diameter, lists labor costs and fixed and variable costs for equipment, and cites time per tree and time per cord figures for several harvesting operations.

Jawetz, P., "The Economic Realities of Alcohol Fuels," The Sugar Journal (January, 1980). (Found in HR Hearings 2/22/80, Oversight/Alcohol Fuels).

This article argues that the octane-improving quality of ethanol must be considered when evaluating the economics of gasohol. In the making of premium unleaded, one gallon of ethanol replaces 1.6 gallons of regular unleaded.

JBF Scientific Corporation, "Evaluation of Processes for Producing Gasoline From Wood." Washington, D.C.: DOE, Advanced Energy Systems Division, Office of Policy and Evaluation, #DOE/PE/70048-72 (1980).

If the United States is to diminish or eliminate petroleum imports, it must pursue: (1) conservation, (2) production of conventional fuels from unconventional feedstock sources, and (3) development of unconventional energy production systems. This report describes several production processes for producing conventional fuels (gasoline and alcohol) from wood. This assessment considers: (1) the extent to which these processes can contribute to fuel supply, (2) the energy and economic costs involved with these processes, and (3) strategies available to accelerate commercialization if one or more of the processes is judged to be worthy of implementation. Technical and economic comparisons among several biomass gasification processes are made. Methanol production from wood appears the most promising. (Author's abstract).

Johnston, B.D., Fuel and Energy Use in a Coastal Logging Operation. Vancouver, British Columbia: Forest Engineering Research Institute of Canada (1979).

Keays, J.L., "Biomass of Forest Residuals," Forest Product Residuals, AICHE Symposium Series 71 (146). New York, New York: American Institute of Chemical Engineers (1975).

Knapton, D.A., An Investigation of Truck Size and Weight Limits, Technical Supplement, Vol. 3: Truck and Rail Fuel Effects of Truck Size and Weight Limits. Cambridge, MA: U.S. DOT, Transportation Systems Center (July 1981).

Koch, P. "Harvesting Energy Chips from Forest Residues — Some Concepts for the Southern Pine Region," U.S.D.A., U.S. Forest Service, Southern Forest Experiment Station, General Technical Report SO-33 (1980).

Residues from southern forests include tops, branches, central root systems, brush, cull trees, trees of unmerchantable species, and trees too small for economic harvest by conventional methods. Before such residues can be used by industry to produce energy, they must be reduced to chip form and delivered to mill stockpiles at a cost that will permit proposed wood-energy processes to operate competitively. Processes, for which wood chips are the feedstock, include combustion, gasification, pyrolysis, liquefaction, and hydrolysis and fermentation.

This paper describes and illustrates about a dozen harvesting methods which can be classified according to procedure as follows:

- Chip whole trees at the stump.
- Extract sawlogs at the stump; bunch and forward branches.
- Chip whole trees at the landing.
- Extract sawlogs at the landing; then chip, chunk, or bale branches.
- Chip residues at the mill.
- Transport complete trees to the mill (stem, crown, roots, and foliage); at mill, divert tree portions to use of highest value.

The cost of energy chips delivered into mill stockpiles, including 30-percent pretax profit on harvesting investment, will likely range from $18 to $33 per ton (green-weight, 1980 basis). (Author's summary).

Lanouette, W. J., "Gasohol No Longer a Laughing Matter as Carter Presses for More Production," National Journal (February 9, 1980).

This article contains a boxed story on the net energy balance. The article cites studies by DOE, NAFC, Katzen Associates and Battelle/API without coming to a conclusion on the energy balance.

Larson, W.E., "Crop Residues: Energy Production or Erosion Control?" Journal of Soil and Water Conservation 34:2 (1979).

How much potential energy is contained in crop residues? How best can crop residues be used? A team of U.S. Department of Agriculture scientists computed where crop residues are produced in abundant quantities, what plant nutrients the residues contain, and the effects of tillage and residue management on wind and water erosion as well as water runoff. The team also estimated how much residue could be removed from the land without exceeding soil erosion tolerance limits. This article and the seven articles that follow it present the details of these studies. (Author's abstract).

Lindstrom, M.J.; Gupta, S.C.; Onstad, C.A.; Larson, W.E.; and Hoft, R.F., "Tillage and Crop Residue Effects on Soil Erosion in the Corn Belt," Journal of Soil and Water Conservation 34:2 (1979).

We calculated potential soil erosion by water for major land resource areas (MLRAs) in the Corn Belt using the universal soil loss equation and current cropping practices. Annual erosion rates ranged from 44.7 metric tons per hectare (19.9 t/a) in MLRA 107 to 9.7 metric tons per hectare (4.3 t/a) in MLRA 103 for a conventional fall-plow, spring-disk tillage system with all residues removed. With no conservation practices applied, only 36 percent of the cultivated area in the Corn Belt would have a soil erosion rate less than or equal to the allowable limits established by the Soil Conservation Service. Use of tillage and residue management systems increases this area to 78 percent. When soil erosion is the only restraint, the maximum amount of residues that can be removed from cropland in the Corn Belt is 58 percent of the total produced. Most of this is located in 4 of the 14 MLRAs. However, variations in residue production and the erosion index within MLRAs pose serious limitations to removal of large amounts of residues for other uses. (Author's abstract).

Little, Arthur D., Inc., Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume XV. Fertilizer Industry Report. Springfield, VA: NTIS, #PB-264 281/7ST (1976).

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes. Volume 15 deals with the fertilizer industry and examines two areas in which energy conservation and pollution control are in conflict: the reduction of nitrogen oxide emissions from nitric acid plants and switching from natural gas to fuel oil for firing fertilizer dryers where emissions are presently controlled by bag filters. (Data base abstract).

Lockeretz, William, Using Crop Residues to Provide Alcohol (May 1980). (To be published by NTIS.)

Martin, W., "Residues-Erosion vs. Energy," Agricultural Research (April 1980).

This article describes the research of Edward Skidmore, who has developed estimates of average annual residue production in 29 MLRAs in the great plains.

Skidmore estimated available residues from wheat, barley, oats, corn and sorghum from 1973-75 average yields of those crops. He then subtracted the estimated amount of applied residue that would be lost from tillage and weathering. He compared that result with the amount needed to control wind erosion in each MLRA as determined by computer solution of a USDA wind-erosion equation.

The author quotes Skidmore as saying that oats, barley and sorghum do not produce large quantities of residue in excess of what is needed to control wind erosion. The author softens that statement by noting that such a generalization does not take into account localized or field-by-field differences. However, it would be accurate for large areas (such as the area needed to supply a methanol conversion facility).

Meekhof, R.; Gill, M.; and Tyner, W., Gasohol: Prospects and Implications. Washington, D.C.: USDA AER #458 (June 1980).

This study emphasizes the economics of alcohol and gasohol production. The study makes projection of the effects of increased production of alcohol on crop volumes and prices.

Middleton, P.; Argue, R.; Burrell, T.; and Hathaway, G., "Canada's Renewable Energy Resources: An Assessment of Potential." Toronto, Canada: Middleton Association (1976).

Rising costs of conventional, frontier, and nuclear energy production and the prospect of future shortages have prompted a resurgence of interest in alternative, renewable energy technologies. This study constitutes a preliminary step in determining which sources, technologies, and applications may be appropriate in Canada and when and under what conditions they might be technically and economically viable. Principal sources of renewable energy (solar radiation, wind, and biomass), as well as waves, thermal gradients and, sensible heat sources are reviewed to establish, in general terms, their significance in the Canadian context. Next, the technical characteristics, efficiency, costs, impacts, and state of the art of sixteen harnessing or conversion technologies are presented as an information base upon which to build an assessment of potential. A method of comparing the life cost of a renewable energy system to that of the likely conventional alternative is proposed and applied in cases where adequate technical and economic data are available. A variety of different economic assumptions are also outlined under which the renewable systems would be cost competitive. This costing methodology is applied in detail to four Case Studies: solar space and water heating — residential; photovoltaics — residential; wind generator — 200 kW; and anaerobic digestion of livestock wastes. Finally, the potential for renewable energy approaches in Canada is explored and evaluated from three perspectives: technical viability, economic viability, and implementation. (Author's abstract).

MITRE Corporation, Silvicultural Biomass Farms Volume I: Summary Technical Report #7347. Washington, D.C.: U.S. Energy Research and Development Administration, Division of Solar Energy (1977a).

This volume summarizes a six-volume report on the silviculture energy farm concept as a potential source of wood/bark biomass for conversion to useful energy products. The report discusses energy farm design, site selection, species selection and needed productivity, biomass farming costs, and energy budget

analyses. It also identifies needed research areas for the development of silvicultural biomass farms to commercial status within a reasonable time frame.

MITRE Corporation, Silvicultural Biomass Farms Volume III: Land Suitability and Availability Technical Report #7347. Washington, D.C.: Energy Research and Development Administration, Division of Solar Energy (1977b).

Land suitability criteria were developed and used to identify potentially available land for silvicultural biomass farms. Six land availability scenarios were chosen for analysis. The annual potential production of biomass energy was estimated on a regional basis assuming the use of 10 percent of the potentially available land in each of the six scenarios and estimated biomass yields. Ten hypothetical biomass farm sites were selected and described.

MITRE Corporation, Silvicultural Biomass Farms Volume IV: Site-Specific Production Studies and Cost Analyses Technical Report #7347. Washington, D.C.: U.S. Energy Research and Development Administration, Division of Solar Energy (1977c).

This report evaluates the concept of silviculture energy farms for the production of wood/bark feedstocks for conversion into useful energy products by selecting 10 sites representing a variety of climatic, topographic and land use situations. Six of the ten sites were representative of "preferred" site conditions or of locations where plantings might reasonably be placed in the future. The authors developed estimates of yield, farming costs, energy inputs, and energy outputs for these ten sites.

Monteith, D.B., "Energy Production and Consumption in Wood Harvest," CRC Handbook of Energy Utilization in Agriculture, pp. 449-464. Boca Raton, FL: CRC Press, Inc. (1980).

This chapter provides a variety of energy balance tables for a wide range of forest conditions, management practices and type of harvest.

Mudge, L.K. et al, Investigation of Catalyzed Steam Gasification of Biomass, Battelle Pacific Northwest Laboratory, Report PNL 3695. Washington, D.C.: U.S. Department of Energy (January 1981).

Mueller Associates, Inc., Price/Cost Parity Between Ethanol and Petroleum, Baltimore, MD (July 1979).

This analysis reviews data on the relationship between the price of petroleum and the price of corn, using data from the Energy and U.S. Agriculture, 1974 Data Base and a 1974 Bonner and Moore Associates' Study. Cost data for ethanol production came from Midwest Solvents' Kansas plant.

The results employ assumptions that favor the economics of ethanol production, and therefore the authors warn that the parity price of gasohol is probably higher than the value found — approximately $47/bbl. of crude petroleum, if the ethanol is produced in a coal-fueled plant.

Valuable data sets in this report include:

- A chart of energy consumed in MBtu/acre and Btu/gallon ethanol vs. fuel type.
- A chart of costs per gallon of ethanol and gasohol distilled by steam from oil and coal vs. the price of crude petroleum.

Municipal Environmental Research Lab, "Fuel and Energy Production By Bioconversion of Waste Materials: State-of-The Art," by Ware, S.A. Silver Spring, MD: Ebon Research Systems (August 1976).

This report is a state-of-the-art summary of biological processes for converting waste cellulose materials (agricultural, municipal and lumbering wastes) to fuels. It indicates the locations and quantities of suitable wastes and discusses the status of the current processing schemes. The processes discussed are: Acid hydrolysis followed by fermentation; enzyme hydrolysis followed by fermentation; anaerobic digestion of manure and municipal solid waste; and, biophotolysis. (Data base abstract).

Onstad, C.A., and Otterby, C.A., "Crop Residue Effects on Runoff," Journal of Soil and Water Conservation 34:2 (1979).

Crop residues on the soil surface decrease runoff from all storm sizes and eliminate runoff from most small storms. Runoff reductions and consequent increases in soil water storage are greatest on less permeable soils. The increase in soil water storage is greatest in the southeastern U.S. (Author's abstract).

Office of Technical Assessment, "Land Availability," Energy from Biological Processes, Vol. II — Technical and Environmental Analyses. Washington, D.C.: Office of Technology Assessment (1980).

This chapter discusses marginal lands available for biomass. Cropland is defined as "land used for the production of adapted crops for harvest, alone, or in a rotation with grasses and legumes."

The authors use Soil Conservation Service 1977 data.

Pettersson, E., "Bio-Energy in Sweden," Bio-Energy Conference Proceedings. Washington, D.C.: Bio-Energy Council (1980).

This article provides a description of Sweden's planned use of biomass resource for energy.

Pimentel, D., Handbook of Energy Utilization in Agriculture. Boca Raton, FL: CRC Press (1980).

Pimentel, D., et al, "Biomass Energy from Crop and Forest Residues," Science 212, pp. 1110-1115 (June 5, 1981).

Plummer, G.M., "Harvesting Cost Analysis," Logging Cost and Production Analysis Timber Harvesting Report #4. Long Beach, MS.: Forestry and Harvesting Training Center, USM Gulf Park Campus (1977).

This source presents various methods of analyzing factors of costs and production in logging for use in logging production analyses, and reports data collected over several years of field analysis from several forest product companies and universities.

Posselius, J. and Stout, B.A., "Crop Residue Availability for Fuel," East Lansing, MI: Michigan State University Agricultural Engineering Department (August 1980).

This paper presents a computer program that takes into account all relevant factors and calculates the amount of crop residue available from each individual field. The most apparent limitations of the computer program are how well the data input reflects the actual system and the users knowledge of the area being

analyzed. A brief look at crop residues role in soil maintenance and the methodology used in this program will help resolve the limitations. (abbreviated author abstract).

Quinney, D.N., "Economics of Utilizing Residues From Logging—Problems and Opportunities," Forest Product Residues. AICHE Symposium Series 71 (146). New York, New York: American Institute of Chemical Engineers (1975).

Ranney, J.W. and Cushman, J.H., "Silvicultural Options and Constraints in the Production of Wood Energy Feedstocks," Bio-Energy Conference. Washington, D.C.: Bio-Energy Council (1980).

Producing wood for use as energy feedstock is neither simple nor clearly economically competitive with alternative fuels or other users of wood at this time although its local availability can dictate its use for energy. Preliminary evaluations of existing wood vegetation, climatic and soil limitations, land availability, existing wood use, and silvicultural (forestry) management alternatives indicate that the United States could annually produce the equivalent of about 10 exajoules of wood for energy almost immediately and perhaps 13-15 exajoules by the year 2000 — a significant energy source. Schemes for production to reach these figures range widely in energy investment, energy return, compatibility with local site conditions, and regional productive capability. Major barriers to the production of wood for energy include collection/procurement methods, environmental impacts, and viability of using wood feedstocks of fuel versus other uses. (Author's abstract).

Robertson, L.S., and Mokma, D.L., "Crop Residue and Tillage Considerations in Energy Conservation" (East Lansing, MI: Michigan State University Extension Bulletin E-1123, February 1978).

Robinson, J.S., ed., Fuels From Biomass-Technology and Feasibility. Park Ridge, NJ: Noyes Data Corporation (1980).

This book contains excerpts on magnitude and location of biomass sources and specifics on the quantities of forestry residues, including amounts, composition, etc. The book also: (1) includes logging and mill residues; (2) presents some cost data on forestry residues; (3) discusses the energy farm concept in general and silvicultural biomass farms in particular: (a) the design concept; (b) tree species considered; (c) distributions, yields; (d) characteristics; (e) process elements; (f) constraints, (g) energy consumption; (h) projections of current trends.

Rocks, L., Fuels for Tomorrow. Tulsa, OK: Pennwell Books (1980).

This book assesses synfuels and other potential fuel sources. In the chapters on alcohol fuels, the author presents a brief discussion of the various alcohol synthesis methods.

Rose, A.B., Energy Intensity and Related Parameters of Selected Transportation Modes: Freight Movements. Springfield, VA: NTIS, # 0RNL-5554 (June 1979).

A study was undertaken to determine the causes of the divergences among published energy intensity values and to prepare a set of consistent values. This volume presents the findings in relation to the freight transportation modes. After a brief overview of the important factors to be considered and the potential pitfalls facing users and analysts of energy intensity values, each of the

major means of freight transportation — air, marine, pipelines, rail, and truck — is discussed. In each of the chapters, after a critique of the available data sources, a consistent time series of operational data and energy intensity values is presented for the major sectors of each mode. In addition, the energy-use effects of the major operational and hardware parameters are quantified so that the given energy intensity values may be modified to reflect a variety of possible changes in the transportation systems. Finally, matrices giving the great-circle distances and modal circuity ratios among the 50 largest standard metropolitan statistical areas are included to facilitate intermodal comparisons. (Author's abstract).

Ruthenburg, K., and Dunwoody, J.E., Agricultural Energy Requirements and Land Use Patterns in Illinois. Springfield, IL: Illinois Dept. of Business and Economic Development, Springfield Division of Energy (1976).

This report was undertaken by the Illinois Division of Energy to evaluate the energy impact of remaining agricultural production caused by withdrawing land from agricultural production. An assessment was made on the energy impact in terms of the additional energy needed to produce more corn and soybeans on less area of land. Both direct and indirect energy impacts have been assessed. (Data base abstract).

Schnittker Associates, Ethanol: Farm & Fuel Issues. Washington, D.C.: National Alcohol Fuels Commission (1980).

The current U.S. and world grain situations are described as well as adjustments which would be likely for fuel production of 1, 2 and 4 billion gallons of ethanol annually in the 1985-86 period. Predicted acreage shifts in corn, soybeans, wheat, and the total of seven major crops are shown. The most likely effects on the feed grains markets both here and abroad are discussed. The value of corn for fuel both with and without the gasoline tax exemption is compared to the actual farm price expected if in the base case (1 billion gallons) real corn prices do not rise. In the higher 2 and 4 billion gallon cases, increases in the real cost of corn and its impact on food prices and the CPI are estimated. A theoretical maximum level of ethanol production recognizing market factors is discussed in terms of acreage, yield, corn production and the fuel ethanol available. Agricultural and other policy frameworks are discussed. (Author's abstract).

Segal, M.R., Alcohol Fuels: Methanol, Ethanol, Gasohol, Issue Brief #1874087. Washington, D.C.: Congressional Research Service (1979).

Skidmore, E.L.; Kumal, M.; and Larson, W.E., "Crop Residue Management for Wind Erosion Control in the Great Plains," Journal of Soil and Water Conservation 34:2 (1979).

We delineated those croplands in the Great Plains where crop residues might be removed without exposing the soil to wind erosion. On the basis of grain yield data, we estimated the residues produced per unit of land by crops. We determined mean soil erodibility and climatic factors for each of 29 major land resource areas and used these factors in the wind erosion equation to estimate the residues needed to control wind erosion. The residues produced in excess of those needed for soil conservation depend on the kind and amount of residues, soil erodibility, climate, tillage management, and judgment of erosion and degradation hazard. (Author's abstract).

Smith, D.M. and Johnson, E.W., "Silviculture: Highly Energy Efficient," Journal of Forestry 75:4, p. 208 (1977).

This article presents techniques of intensive silviculture that require increased amounts of oil. More wit, imagination, and intelligence may be forms of administrative attention that can reduce energy consumption. No foundation exists in the implication that intensive silviculture is in the same trap as modern agriculture. Savings possible in nitrogen fertilization and mechanical site preparation of regeneration are discussed. (Data base abstract).

Smith, N. and Corcoran, T.J., "The Energy Analysis of Wood Production for Fuel Applications," Symposium of Net Energetics of Integrated Synfuel Systems. Orono, Maine: University of Maine (1976).

This paper discusses types of wood harvesting equipment; typical production rates and fuel consumption figures for this equipment; energy use in tree length wood production system and a whole tree chip system; and probable energy requirements for a short-rotation wood fuel crop.

Southwide Energy Committee, "Petroleum Product Consumption and Efficiency in Systems for Energy Wood Harvesting," Jackson, MS (1980).

Reports petroleum product consumption for 6 harvesting systems practiced in the southeastern United States. Includes mechanized whole tree harvesting.

Szego, G.C.; Fraser, M.D.; and Henry, J.F., Design, Operation, and Economics of the Energy Plantation as an Alternate Source of Fuels. Warrenton, VA: Intertechnology/Solar Corporation (1978).

This paper discusses the use of an energy plantation to grow plants to be converted to methanol, with this methanol used as a fuel source. The authors estimate the amount and location of land that could be used in such an energy plantation effort. An analysis of the economics of energy plantations includes a breakdown of fuel costs.

Tillman, D.A., Wood as an Energy Resource III Wood Fuel Farms or Plantations. New York, New York: Academic Press (1978).

This source evaluates wood fuel farm or plantation concept, discussing:

- minimum operating conditions
- detailed energy trajectory (energy inputs vs. energy outputs)
- energy efficiencies
- limitations of concept.

The author concludes that a measurable energy contribution from wood energy farming will not occur until the twenty-first century.

TRW, Energy Balances in the Production and End-Use of Alcohols Derived from Biomass. Washington, D.C.: National Alcohol Fuels Commission (1980).

This volume is the most extensive study on the net energy of ethanol. However, the study is limited to the production of inputs from Illinois and a processing plant in Illinois.

Within those limitations, the study considers corn, corn/sweet sorghum, and cellulose; and several fermentation processes fueled by residual oil, natural gas, coal and bagasse. The study finds a positive net energy for all of these cases.

The report also contains data on energy investments in refined petroleum products, natural gas production, coal production and electric power generation.

Tyner, Wallace E., ed., "The Potential of Producing Energy from Agriculture," Energy From Biological Processes Vol. III - Appendixes. Washington, D.C.: Office of Technology Assessment (September 1980).

Tyson, Belzer and Associates, 1979 Energy Use Survey. Washington, D.C.: The Fertilizer Institute (1980).

This source provides tables of energy consumption by type of fertilizer and type of fuel.

U.S. Department of Agriculture, Economic Research Service, Structure of Six Farm Input Industries. Washington, D.C.: USDA, ERA-357 (1968).

This pamphlet presents ten pages of information on each of the following six industries:

- Petroleum
- Farm Machinery and Equipment
- Fertilizers
- Chemical Pesticides
- Livestock Feeds
- Farm Credit

For each industry, the pamphlet describes the relationship between that industry and the farm industry. This includes the dollar input into farming from each industry, as well as the unit input.

For this study, the pamphlet lists the plant locations of major fertilizer mixing plants.

U.S. Department of Agriculture, Agricultural Statistics, 1978. Washington, D.C.: GPO (1978).

U.S. Department of Agriculture, Soil and Water Resources Conservation Act: 1980 Appraisal, Review Draft, Part II. Washington, D.C. (1980).

Contains maps and descriptions of Major Land Resource Areas (pp. 7-18 through 7-21).

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16 Abstract
In this study, energy requirements for producing alcohol fuels are estimated and are compared to the energy content of the alcohol produced. The comparisons are developed for three alcohol production alternatives: ethanol from grain, methanol from cellulose, and methanol from coal. In the analysis, alcohol fuel and all nonrenewable fuels are valued on the basis of their higher heating value (in Btu), while byproducts and grain and cellulose feedstocks are valued on the basis of the effect their production would have on the consumption of nonrenewable fuels. The effects of changes in agricultural production were analyzed on the basis of their effects on overall agricultural energy consumption (not on average energy consumption associated with present production). All three alcohol production alternatives were found to be effective means of increasing supplies of liquid fuels. The cellulose-to-methanol alternative, however, produces more energy than it consumes. (The favorable energy balance for this feedstock results largely from the use of cellulose as a boiler fuel as well as a feedstock.) The grain-to-ethanol alternative yields a slightly negative energy balance, while the coal-to-methanol alternative (which uses a nonrenewable fuel as both feedstock and boiler fuel) results in a substantially negative energy balance. The report is presented in four volumes. Volume I (NASA CR-168090) contains the main body of the report, and the other three volumes contain appendices:

II - Appendices A and B: Ethanol from Grain (NASA CR-168091)
III - Appendices C to F: Methanol from Cellulose (NASA CR-168092)
IV - Appendices G and H: Methanol from Coal (NASA CR-168093)

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